

Irrigation and Autocracy

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Abstract

Irrigated agriculture makes societies more likely to be ruled by an authoritarian elite. This effect has been hypothesized by many European intellectuals over the centuries. We use statistical methods to demonstrate that the effect exists across countries, within countries, and across premodern societies surveyed by ethnographers. To avoid endogeneity, we use geographical and climatic variation to identify irrigation dependent societies. We find that countries whose agriculture entirely depends on irrigation are about six points less democratic on the 21-point polity2-scale than countries where agriculture is rainfed. Our results reflect that irrigation allows landed elites in arid areas to monopolize water and consequently arable land. That makes elites more powerful, and better able to oppose democratization than their peers in rainfed societies. Consistent with this conjecture, we show empirically that historical land inequality is an important mediator for the effect of irrigation dependence on present institutions.

KEYWORDS: Democracy, resource curse, institutions, irrigation.

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1 Introduction

We show empirically that societies whose agriculture has been based on irrigation are more unequal economically and politically than societies with rainfed agriculture. Irrigation allowed landed elites to monopolize water in areas with little rain, and they could consequently extract monopoly rents from peasants working their land. Irrigation-based societies thereby became more unequal than rainfed societies, and the high inequality made democracy less likely to take root.

The idea that irrigation leads to oppressive institutions is not new. It is part of Karl Marx’s theory of the Asiatic Mode of Production, but the idea is most forcefully articulated by Karl August Wittfogel in his book *Oriental Despotism*.¹ Marx and Wittfogel analyze a few historical case studies of centralized and despotic states underpinned by irrigation, such as ancient Egypt, Mesopotamia, India, China, the Chagga (Tanzania), and the pre-columbian Andean and Mexican civilizations. We are the first to go beyond the historical case studies and use statistical methods to test the link between irrigation and present-day institutions.

We need to distinguish between societies based on irrigation and societies based on rainfed agriculture in our empirical analysis. The extent of irrigation is likely to be endogenous, however, as authoritarian leaders may be more willing and capable of undertaking large scale irrigation works. To rule out reverse causality, we use a measure of irrigation *potential* based on exogenous geographical and climatic variables to identify societies that were based on irrigation historically.

In the first part of our empirical analysis, we show that countries with a high irrigation potential are more likely to be autocratic today as measured by the *polity2* index from the Marshall *et al.* (2010) Polity IV database. Our estimates imply that on the 21 point *polity2*-scale of democracy, a country with only rainfed agriculture is about six points more democratic than a country with only irrigated agriculture. The results are robust to a wide range of control variables capturing variation in geography, climate, resource endowments, development, religion, and colonial history. Colonization dilutes the effect of irrigation somewhat, consistent

¹Marx (1853) and Wittfogel (1957). Marx and Wittfogel were inspired by earlier writings on irrigation by prominent intellectuals ranging from Aristotle and Herodotus, to Montesquieu, Hegel, Adams Smith, and John Stewart Mill. See O’Leary (1989) for an account of the history of thought on the Asiatic Mode of Production.

with a lasting impact of European presence on institutions.²

To check the robustness of our results to possible unobserved confounders at the country-level, we move to subnational evidence in the second part of our analysis. We demonstrate that respondents in the World Values Survey are less likely to view democracy as the best form of government if they live in districts with high irrigation potential.

We argue that our results are caused by the fundamental differences between irrigated and rainfed agriculture: Irrigated agriculture depends on dams, canals, and other costly infrastructure. In premodern societies, without well-functioning capital markets, only a monarch or members of local feudal elites could command the necessary resources to invest in large scale irrigation. By owning the irrigation infrastructure, the elites gained a natural monopoly over water in areas with little rain. This monopoly caused a concentration of land ownership. Not just because the elites were more likely to build irrigation systems in hitherto barren areas as they themselves owned the land. But also because absentee landlordism became more attractive by irrigation. Tenants, who could not afford to construct irrigation systems themselves, had few outside options in areas where irrigation was a necessity. This increased the bargaining power of land owners, and consequently the potential for rent-seeking. The potential for rent-seeking by land owners was amplified by the spatial concentration and predictable yields of irrigated agriculture which reduced the costs of monitoring tenants.³

To support our argument we proceed to demonstrate that a concentration of land ownership did exist historically in areas with irrigation. In a sample of premodern societies surveyed by ethnographers, we find that societies whose agriculture was based on irrigation were about 30 percentage points more likely to be ruled by an elite. We find the same pattern in country-level data from the middle of the 20th century: land inequality was significantly higher in countries with a high irrigation potential. Consistent with the transmission mechanism we propose, we demonstrate a link from historical land inequality to present autocracy. We do so by using irrigation potential as one of two instrumental variables for land inequality. The other instrument is the suitability for cereals relative to plantation crops, a group of crops

²*E.g.*, Acemoglu *et al.* (2001), Feyrer & Sacerdote (2009), Olsson (2009), Dell (2010) and Hariri (2012).

³Mayshar *et al.* (2012).

which are known from prior studies to increase land inequality.⁴ Instrumented historical land inequality exerts a large and statistically significant effect on the *polity2*–index of democracy. Moreover, the use of two instruments allows us to test the exclusion restrictions by a Hansen overidentification test. The test rejects the null that irrigation potential has an effect on the *polity2*–index of democracy beyond its effect on land inequality. The overidentification test has low power, but the result is consistent with our hypothesis that irrigation concentrated wealth and land in the hands of a landed elite opposed to democracy. The elite set up oppressive institutions to protect their natural monopolies of water and land. They were particularly opposed to democracy out of fear that enfranchised peasants would vote for land reform. Large land owners were, for instance, among the main supporters of the authoritarian regimes in North African countries prior to the Arab spring.⁵ In Pakistan, much of the political elite derives from the class of big landholders in the heavily irrigated Indus basin, and they have successfully thwarted many attempts at land reforms.⁶

Our paper is related to studies by Engerman & Sokoloff (1997, 2000, 2002, 2005) of how agriculture put temperate America and tropical America on different development trajectories.⁷ Tropical crops such as sugar, bananas, and coffee could profitably be grown on large scale plantations using slave labor. By contrast, plantations and slavery were not viable in the temperate parts of the Americas where cereals were the main crops. As irrigation, the plantation system created a powerful landed elite who successfully prevented the emergence of democratic institutions akin to the ones that took hold in the United States and Canada.

Our paper is also related to studies by Haber (2012) and Welzel (2014), who both demonstrate a link between rainfall and democracy.⁸ Democracies are, according to Haber (2012), found in areas with moderate rainfall. Moderate rainfall is conducive to cereal production characterized by small minimum efficient scales, low barriers to entry, storability, and high local variation in output. The first two characteristics provide opportunities for small independent farmers, and the other two opportunities for accumulation and trade. This gave

⁴See, *e.g.*, Easterly (2007) and the discussion below.

⁵King (2007).

⁶Malik (2010).

⁷See also Lagerloef (2004), Easterly (2007), Soares *et al.* (2012), and Ager (2013).

⁸Haber (2012) is a revised version of an earlier paper by Haber & Menaldo (2010).

rise to relatively egalitarian societies who would favor property rights and constraints on the executive.

Irrigation systems are usually large in scale, and the high fixed costs are a barrier to entry. So the hypothesis we test in this paper is embedded in the multifaceted theory of Haber (2012). We run a horse race regression between the impact of irrigation potential and that of a nonlinear effect of rainfall use to test his theory Haber. Both effects have a significant impact on the *polity2*-index when included separately in regressions, but rainfall becomes insignificant when they are included together.

Welzel (2013, 2014) shows that temperate societies with plenty of rainfall tend to be more democratic, have stronger preferences for freedom, and develop faster economically. The first part of the explanation is, according to Welzel, water autonomy: rain made fresh water available to everyone, which, among other things, prevented the centralization of irrigated societies. The second part of the explanation is that cool weather curbed the spread of diseases. In this paper, we confirm the first conjecture by testing the irrigation hypothesis directly.

The link between irrigation and autocracy is an example of the resource curse, *i.e.*, the empirical finding that natural resource abundance curses societies with poor institutions. Oil is the classic example, cf. Ross (2001, 2012), but hardly the only one. Numerous scholars, including Auty (2001), Isham *et al.* (2005), Bulte *et al.* (2005), Boschini *et al.* (2007), and Williams (2011), have shown that broad measures of oil, mineral, and plantation crops wealth are associated with poor institutions in developing countries. What oil, minerals, and plantations crops have in common with water for irrigation is that they are "point-source" resources, *i.e.*, resources that are easy to monopolize. Cereals and other crops grown in irrigated areas may be less valuable than oil or gold, but food production has been the main economic activity for most of human history. So it is, perhaps, not surprising that we find that irrigation has at least as large effect on institutions as the other point source resources studied in the literature.

2 Irrigation: a mixed blessing

Before we begin a detailed discussion of irrigation and institutions, a small note on terminology is warranted: We use the term "irrigation" as shorthand for traditional irrigation methods based on surface water and gravity. The advent of diesel and electric motors in the 20th century gave farmers access to a new source of power, and hence a new source of water: ground water pumped from aquifers. This permitted a different sort of irrigation based on wells drilled by individual farmers which did not have the same impact on institutions as traditional irrigation methods. Economic development and other 20th century technologies also made irrigation viable in many areas with no history of irrigation. We discuss modern irrigation techniques in Section 3, where we introduce our measure of irrigation potential.

2.1 A natural monopoly

Irrigation can turn barren land into fertile fields. In warmer climates, irrigation may allow for multiple harvests every year in areas where the local rainfall permits only one or none at all. But irrigation has drawbacks, too. Irrigation infrastructure can profitably be monopolized by a rent-seeking elite, just as oil-drilling and mining in developing countries tend to be. One reason is that irrigation systems require large fixed costs to construct, and the gains are often spread across many farmers and over many years. Absent well-functioning capital markets, local land lords or centralized governments are in a better position to finance the construction of irrigation systems than individual farmers, and consequently to claim ownership. The geographer Commodore B. Fisher observed this firsthand in early 20th century Persia:

"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."⁹

Because peasants were unable to construct their own irrigation system, they had no other choice than to rely on the ones owned by the landed elite. The elite therefore gained a local natural monopoly over water. As described in the quote by Commodore B. Fisher, the local monopoly of water essentially amounted to a monopoly of fertile lands. Absent any modern regulation of natural monopolies, the owners of irrigation systems were free to extract monopoly rents from the peasants. And rent-seeking led to a more unequal distribution of wealth.

The scope for rent-seeking is amplified by other characteristics of irrigated agriculture: Predictable high yields, and production in confined geographical areas. Yields are predictable since the amount of water allocated to each plot is observed and deliberate.¹⁰ In medieval Egypt, for example, accurate estimates of yields were calculated in advance by observing the height reached by the annual floods, and taxes were set accordingly.¹¹ Predictable yields and the spatial concentration of irrigation reduce the costs of monitoring agricultural production, and absentee landlordism based on sharecropping or serfdom thereby become attractive. Land owners do not need to monitor effort directly. Shirking can be prevented by promising severe punishment if the sharecropper or serf fails to produce the amount of crops predicted by the water allocated to his plot. Large landholdings are therefore more attractive in irrigated societies than in rainfed areas and, as a consequence, a centralization of land ownership is more likely to occur.

Mayshar *et al.* (2012) formalize this mechanism in a principal-agent model, and apply it to a case study of ancient Mesopotamia.¹² Agriculture in Lower Mesopotamia (Babylonia) was fed by water from Tigris and Euphrates, and land ownership was concentrated within a small, but powerful elite. By contrast, agriculture in Upper Mesopotamia was rainfed, and independent owner-occupied farms were prevalent. Braudel (1972) similarly describes how a traveller in 16th century Spain "passing from the *secanos* to the *regadíos* - the dry to the irrigated zones -

⁹Fisher (1928).

¹⁰Mayshar *et al.* (2012).

¹¹Cooper (1976).

¹²The case study builds on Renger (1995). The model also predicts under which conditions an irrigation-based society becomes centralized, as with the Pharaohs in Egypt, or decentralized, as in Mesopotamia where the local landed elites had more power relative to the center. This part of their analysis concerns the distribution of rents amongst the elite. We are interested in how large rents the elite is able to extract from the peasants.

left behind a relatively free peasant to find a peasant slave."¹³ The same pattern is found in a quantitative study of early 20th century Punjab by Islam (1997). He shows that the correlation between the share of land with canal irrigation and the share of land tilled by tenants rather than independent farmers is 0.58 across districts. Serfdom and sharecropping also appear to have been the norm in the ancient societies as discussed by Wittfogel (1957).

Archaeologists and anthropologists give numerous examples of societies where an elite based their power on irrigation.¹⁴ Hayashida (2006) describes a society existing from around 900-1532 AD in the Pampa de Chaparrí on the North coast of Peru. The society was governed by a hierarchical system of lords who distributed water to the local farmers in return for corvée labor. Another example is the princely state of Hunza in Pakistan, established by Mir Silim Khan in 1790.¹⁵ When Silim Khan came to power, he ordered the construction of massive irrigation systems. The allocation of water to each Hunza village was overseen by a hierarchy of officials, who also directed when villagers should plant, harvest, and do maintenance work on the irrigation infrastructure. The irrigation system generated large amounts of revenue for the Mir and his officials. In that respect, the Hunza state resembles modern Uzbekistan. A major source of revenue for the Uzbek government derives from its control of the country's irrigated cotton fields.

Both the Hunza state and modern Uzbekistan are examples of centralized despotic states of the kind envisioned by Marx and Wittfogel. Yet, irrigation needs not lead to centralization at the national level. Irrigation systems have to be managed locally, and, as we have argued above, this management was often firmly in the hands of a local landed elite. The degree of centralization depends on the circumstances. For instance, whether the elites find centralization to be desirable, or how well a central government can monitor and tax the landed elite.¹⁶ Centralization or not, irrigation concentrated land ownership in the hands of an elite with no interest in democracy.

¹³Braudel (1972), page 75.

¹⁴See Mitchell (1973) and Hunt & Hunt (1976) for an overview of the literature, including some counter-examples.

¹⁵See Sidky (1997).

¹⁶See Mayshar *et al.* (2012) for a discussion of the latter.

2.2 Impact on national institutions

An elite in control of land or other natural resources risks expropriation, either violently through rebellion, or peacefully at the ballot box. To protect their privileges, they opt for an oppressive regime and fend off calls for democracy. Moreover, the resource rents can substitute for taxation, and thereby make the ruling elite less likely to offer representation in return for tax payments.¹⁷ This is the essence of the institutional resource curse.

Resource abundance may, however, be compatible with good institutions if the resource-owning elite faces opposition from other special interest groups. That is one reason why the resource curse is mostly observed in developing countries with little economic activity outside their primary sectors. Another reason why resources rarely are a curse in developed countries is that many subsoil resources have been discovered within the past century, when many developed countries already had developed institutional constraints on the elite.¹⁸ For instance, oil discoveries in the North Sea have not turned Norway into an authoritarian country, just as oil discoveries in Texas and the Mexican gulf have had little impact on institutions in the United States. Norway and the United States both had solid democratic institutions when oil was discovered, and they both had diversified economies where other special interest groups provided opposition to the oil magnates.

Things were different when oil was discovered in Africa and the Middle East.¹⁹ Democratic institutions were fragile or non-existent, and the ruling elites were in a good position to turn the oil bonanzas into personal cash cows. Some of the resulting financial gain was used to set up institutions that protected their oil wealth, and to entrench their power further.

In contrast to oil extraction, irrigation is an old technology mastered in ancient Mesopotamia. So few nations, if any, had institutions that provided checks and balances on the ruling elite when irrigation was first introduced. Moreover, all societies that adopted irrigation were agrarian, so the irrigation rents represented a significant share of total income. And with a negligible nonagricultural sector, the irrigation owning elite faced little opposition from other

¹⁷Bates & Lien (1985).

¹⁸See, *e.g.*, Boschini *et al.* (2007) and Mehlum *et al.* (2006). The same argument can be made about modern irrigation techniques. See Section 3.

¹⁹See Ross (2001), Ross (2012).

special interest groups. All requirements for a resource curse were in place.

2.3 Institutional persistence

Agriculture accounts for an ever declining share of world output, and so too do irrigation rents. But the uneven distribution of power and wealth in irrigation-based societies may nevertheless persist after the societies develop and industrialize. The elite can, for example, use their fortunes and political power to get a grip on emerging sectors such as manufacturing, utilities, and banking. They have the financial muscle to do so directly through investment or acquisition. But intermarriage with the emerging urban elite also appears to be a conscious strategy for big land owners, at least in the case of Pakistan described by Malik (2010). A similar strategy may have been employed in Algeria, Egypt, Syria, and Tunisia, where the regimes prior to the Arab spring were controlled by coalitions of landed elites and urban elites.²⁰ These elites were more concerned with rent-seeking than democracy, and collaborated to roll back land reforms and nationalizations undertaken by earlier populist socialist movements. The same pattern was found in Chile where the Pinochet regime was supported by both urban elites and irrigation owners expropriated by the previous communist regime led by Salvador Allende.²¹

The landed elite in irrigation based societies were also able to exert substantial influence on the bureaucracy. The unequal distribution of wealth in irrigation based societies meant that it was mainly the large land owners who were able to provide their sons and daughters with the education necessary to reach the higher ranks of the bureaucracy.²² The bureaucracies therefore became dominated by members of the landed elite, who viewed the landed interests favorably during the process of industrialization.²³ In Pakistan, the landed elite were even able to gain control of elected bodies. 105 out of 138 elected members of parliament were in 1970 large land owners, and the landed elite managed to block successive subsequent attempts at

²⁰King (2007).

²¹Bellisario (2007).

²²Inequality of land ownership is known to cause such inequality in educational attainment as well. See Galor *et al.* (2009).

²³See Alam (1974), King (1998) and Jeffrey (2000) for case studies of Pakistan, Tunisia, and India.

land reform.²⁴

Through coalitions with urban elites, and through their influence on government and bureaucracy, the irrigation elites have the means to fend off calls for democracy even after agriculture loses its relative economic importance. The task is made easier since irrigation also bars entry of independent farmers, the natural middle class in an agrarian society, and prime supporters of democracy.²⁵ The opposition to elite rule is therefore weaker than in rainfed societies with large middle classes.

The institutional persistence in irrigation based societies resembles that of the slave-propelled plantation system in the Americas. Engerman & Sokoloff (2000) argue that even when slavery was abolished, plantation owners kept their land and much of their political power.²⁶ Democracy would undermine their political influence and open up the possibility of land redistribution. The plantation owners consequently supported autocratic regimes. Even in the United States did slavery have a lasting legacy on institutions. Lagerloef (2004), Soares *et al.* (2012), and Ager (2013) show that present-day variation in institutional quality and income inequality within the United States can be traced to antebellum slavery.

Inspired by the insights of Sokoloff and Engerman, Easterly (2007) use suitability for wheat cane relative to sugar as an instrument for present-day inequality. Instrumented inequality predicts poor institutional outcomes and economic underdevelopment. It also predicts less schooling, consistent with the model and the results reported by Galor *et al.* (2009).

There are numerous other examples of institutional persistence. Following Acemoglu *et al.* (2001), many studies use the transplantation of institutions during the colonial era as random experiments to identify the effect on present-day outcomes. Dell (2010) shows that the mining mita in Peru, a system of coerced labor abolished in 1812, still exerts a negative effect on land tenure and public goods provision in the affected areas. Iyer & Banerjee (2005) and Iyer (2010) find that the institutions set up by the British in India to collect land revenue have left

²⁴See Alam (1974) and Malik (2010).

²⁵See, *e.g.*, Easterly (2001). The lack of an agrarian middle class is likely to have impeded the rise of an industrial middle class, which in the model of the Industrial Revolution by Doepke & Zilibotti (2008) replaces the landed aristocracy as the dominant class during the process of industrialization.

²⁶The ideas of Sokoloff and Engerman were anticipated by Baldwin (1956) and Earle (1978). See also Isham *et al.* (2005) for a discussion.

their mark on today’s institutions. Olsson (2009) and Hariri (2012), among others, provide cross-country evidence for the persistence of colonial institutions.

Colonizers exported both good and bad institutions to their colonies. As argued by Acemoglu *et al.* (2001), democracy, rule of law, and free trade, are parts of the colonial legacy in the colonies where Europeans settled. But in resource abundant regions where European settlers found the climate and the disease environment unbearable, they set up colonies with the purpose of extracting resource rents. When the Europeans left, local elites took control of the extractive institutions imposed by their former colonizers. That led to an uneven distribution of power and wealth similar to in the irrigation-based societies we study in this paper.

3 Measuring irrigation dependence

To test whether societies with a history of irrigation are more autocratic today, we estimate regressions of the form:

$$institutions_i = \alpha_0 + \alpha_1 irrigation_i + X_i' \beta + u_i , \quad (1)$$

where i indexes the unit of observation, *institutions* is a measure of democracy or land ownership, *irrigation* is a measure of irrigation dependence, X is a vector of control variables, and u is an error term.

The main empirical challenge is to find a measure of historic irrigation dependence. We want to identify societies where traditional irrigation methods at some point in time contributed to a substantial fraction of aggregate income. Consistent country-level data on historical irrigation use do not exist, and the recent emergence of new irrigation technologies have made modern irrigation data a poor proxy. Moreover, even if historical irrigation data existed, the extent of irrigation would be endogenous. Autocratic leaders may, for instance, be inclined to undertake large irrigation works, as they can pocket much of the revenue themselves. They may also be better able to command and coordinate the necessary labor. An estimate of α_1 in Equation (1) could reflect these possibilities, rather than the resource curse mechanism we are testing.²⁷

²⁷This has often been used to criticize Wittfogel (1957), see, *e.g.*, Fukuyama (2011).

To avoid endogeneity bias, and as an alternative to lacking historical data, we compute an exogenous measure of *irrigation potential* to identify societies that depended on irrigation in the past. Variation in our measure of irrigation potential is caused by variation in geography and climate, and not by institutions or other acts of man.²⁸

3.1 Irrigation potential

Our irrigation potential variable is based on data from the Food and Agriculture Organization (FAO)’s global Agro-Ecological Zones (GAEZ) 2002 database. FAO divides the globe into $0.083 \times 0.083^\circ$ (latitude-by-longitude) grid cells, corresponding to 9×9 km at the equator. For each grid cell, FAO calculates the crop, or combination of crops, that maximizes yields in terms of nutritional value.²⁹ The calculations are based on a long list of variables, including temperature and precipitation profiles over the year, cloud cover, altitude, crop-specific evapotranspiration, soil texture, and the slope of the terrain. Crucially, FAO estimates the maximum attainable agricultural yields both under the assumption that rain is the only source of water, and under the assumption that an unlimited supply of water from irrigation is available. The ratio of the maximum attainable yield under irrigation to the maximum attainable yield under rainfed conditions is defined by FAO as the *irrigation impact*:

$$irrigation\ impact = \frac{max.\ attainable\ yields\ from\ irrigated\ agriculture}{max.\ attainable\ yields\ from\ rainfed\ agriculture}$$

Irrigation impact consequently measures the hypothetical increase in yields if irrigation is introduced in an area where agriculture was previously rainfed. The hypothetical increase is independent of the actual technology in use and the actual variety of crops grown.

FAO does not provide irrigation impact as a continuous variable, but divides the world into the five *impact classes* shown in Figure 1. Impact Class 1 is areas where additional water beyond natural rainfall does not increase yields (green areas on the map). Impact Class 5 is

²⁸Our empirical approach resembles that of studies by Easterly (2007), Nunn & Qian (2011) Michalopoulos (2012) and Alesina *et al.* (2013). For example, Nunn & Qian (2011) use agricultural suitability for growing potatoes as a source of exogenous variation in actual potato cultivation.

²⁹See Fischer *et al.* (2002) for data documentation. 154 individual crops are considered in the calculation. See also Nunn & Qian (2011) for a discussion of this methodology.

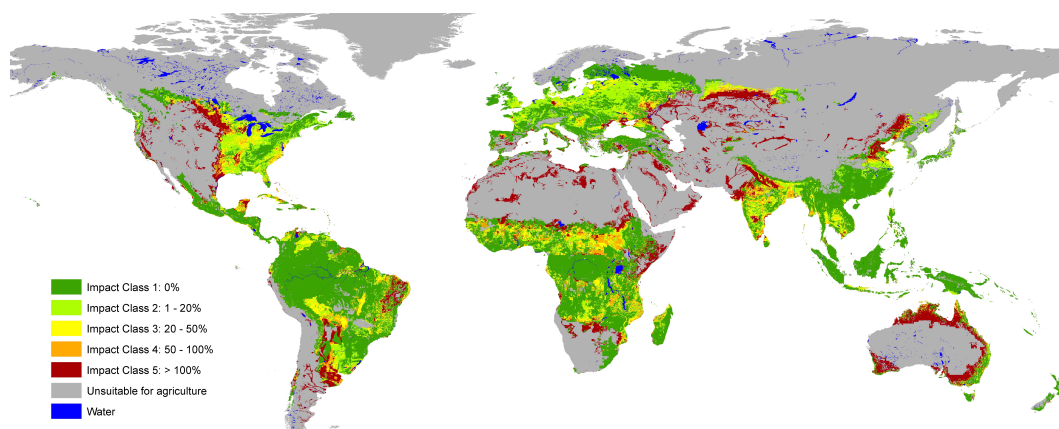


Figure 1: Irrigation impact classes.

Sources: The FAO Global Agro-Ecological Zones (GAEZ) 2002 database.

areas where irrigation can more than double yields (red areas on the map), and impact classes 2-4 are intermediate steps between these two extremes. Areas too cold, too mountainous, too sandy or with no nearby water source are classified as unsuitable to agriculture (grey areas on the map).

Our aim is to identify societies where a landed elite can monopolize water, and thus agriculture, by controlling irrigation systems. Such societies are most likely to be located where no agriculture is possible without irrigation, *i.e.*, in Impact Class 5. We therefore focus on Impact Class 5 in our empirical analysis. Peasants in Impact Class 5 had historically few options but to work on the irrigated land owned by the elite. That made them relatively easy targets for rent-seeking and oppression, and we should therefore expect irrigation to have a greater impact on institutions in societies located in Impact Class 5. In the lower impact classes, agriculture is possible without irrigation, and peasants would not have had to rely on irrigation systems owned by the elite.

A second reason for focusing on Impact Class 5 is that we can be confident that agrarian societies located in Impact Class 5 areas in fact had irrigation historically, since this was the only possible type of agriculture. The same is not true for the lower impact classes, where rainfed agriculture is possible. Moreover, the rapid technological progress of the past century has dramatically reduced the relative cost of constructing irrigation infrastructure and made it profitable to adopt irrigation in many areas with low impact classes. We return to this issue

below, and in the appendix where we show that our empirical results are robust to including Impact Class 4 in our measure of irrigation (Table B1).

For the purpose of our analysis, we need to convert the pixel-level irrigation impact data to a meaningful measure of irrigation dependence measured across larger geographical areas (*i.e.*, countries, regions, and ethnographic societies). To this end, we define the *irrigation potential* of an area as land in irrigation Impact Class 5 as the fraction of land suitable for agriculture:

$$\text{irrigation potential} = \frac{\text{area in impact class 5}}{\text{land suitable for agriculture}}. \quad (2)$$

Land suitable for agriculture is land in either of the impact classes 1-5 on the map in Figure 1, and *irrigation potential* consequently ranges from 0 to 1. Countries with *irrigation potential* = 1 include Egypt, Turkmenistan, and Qatar; countries with *irrigation potential* = 0 include United Kingdom, Denmark, and Macedonia; and countries with intermediate levels of irrigation potential include Argentina (0.42), Jordan (0.54), and Namibia (0.56).

We put land suitable for agriculture in the denominator of Equation (2) since we are interested in the effect of irrigated agriculture *relative* to rainfed agriculture on institutions. Moreover, the institutions of a society are likely to have evolved in areas with the greatest number of people. Malthusian constraints kept population densities low in most areas unsuitable for agriculture. By leaving such areas out of the analysis, we get a clearer picture of the geographical circumstances that shaped institutions in a given society. Dividing by total land instead of land suitable for agriculture in Equation (2) would introduce a measurement error. The vast deserts of Egypt would, for example, make the country seem less dependent on irrigation than it actually is.

Our measure of irrigation potential is based on soil data from around 1990, and climatic averages for the period 1961-1990, but it is nevertheless a good proxy for historical irrigation potential. Climate is highly persistent over time and climate change is exogenous to human activity at the local level. Human activity can, however, deplete the soil. But soil depletion affects the estimated yields of rainfed agriculture and irrigated agriculture proportionally, and the denominator in our measure of irrigation potential is consequently unchanged. The only exception is when soil depletion renders some previously irrigated areas completely unsuitable

for agriculture. This would lower the area in impact class 5 relative to its historical level, and our measure of irrigation potential would then underestimate the extent of historical irrigation. We address this issue in the empirical analyses by controlling for soil constraints and salination.

FAO calculates the attainable crop yields underlying our measure of irrigation potential based on an assumption that an intermediate input level is used. The intermediate input level roughly corresponds to the methods of agricultural production in use prior to the Green Revolution. So our measure captures the potential for irrigation when access to improved crop varieties, fertilizer, and mechanization is limited. Irrigation potential is consequently less affected by recent technological progress than actual modern irrigation.³⁰

3.2 Irrigation potential and irrigation in premodern societies

Are societies with a high irrigation potential more likely to actually have had irrigation? To find out, we compare our irrigation potential data to data on historical irrigation use from the Ethnographic Atlas compiled by Murdock (1967). The Ethnographic Atlas is a data collection based on ethnographic observations from 1267 traditional societies scattered around the globe. The data is coded such that quantitative comparisons of societies can be made. All societies outside Europe are measured before any significant European influence, most in the 19th and early 20th century.

The Atlas contains information on whether a society had agriculture at the time of observation, and whether they used irrigation. In Table 1, we split the agrarian societies into societies with and without irrigation, and show how the two groups were distributed across the irrigation impact classes.

We use the coordinates provided by the Atlas to locate each society. The coordinates are not exact. Rounding errors may cause societies to lie up to 50 km from the given coordinates, and measurement errors may add further uncertainty about the location. Furthermore, a society would typically occupy an area larger than one cell. We therefore follow Alesina *et al.*

³⁰The irrigation impact in a region may be affected by older developments, such as the Columbian Exchange, or the introduction of the steel-tipped plow. Whether such progress increases or decreases irrigation potential is uncertain. The steel-tipped plow, for instance, made agriculture possible in areas with heavy soil. How the plow affected the irrigation potential of a country depends on how the heavy soils were distributed between rainfed and arid areas in the country. We treat such historical developments as measurement errors.

(2013) and compute all geographical variables as averages of cells within 200 km radius of the coordinates reported in the Ethnographic Atlas.

As Table 1 shows, 43% of the societies with irrigation are located in areas where Impact Class 5 is the most widespread of the five impact classes within the 200 km radius. The same is only true for 9% of the societies without irrigation. Further, 85% of the societies without irrigation are located in areas with so much rain that irrigation is redundant.

When we divide locations in terms of the most widespread impact class, we are disregarding local variation in the gain from irrigation. Although 52% of the irrigation dependent societies are located in regions where rainfed agriculture dominates, they may still be located in a pocket where the gain from irrigation is substantial. Indeed, 80% of the societies with irrigation have coordinates close to areas with Irrigation Impact Class 5, and it is likely that the societies were actually located in these particular areas within the 200 km radius. By contrast, only 3% of the societies recorded as having irrigation were located in areas with no potential gain of irrigation within 200 km.

Table 1. Irrigation impact classes versus actual historic irrigation

	Dominant IC within 200 km of societies		Highest IC within 200 km of societies	
	with irrigation	without irrigation	with irrigation	without irrigation
Impact Class 5 (>100% gain)	43%	9%	80%	63%
Impact Class 4 (50-100% gain)	2%	2%	12%	22%
Impact Class 3 (20-50% gain)	2%	2%	4%	4%
Impact Class 2 (1-20% gain)	2%	2%	0%	0%
Impact Class 1 (0% gain)	52%	85%	3%	11%
Number of societies	122	752	122	752

Notes: The impact classes measure how large a gain in yields can be obtained by adopting irrigation, compared to rainfed agriculture. Dominant IC indicates which of the impact classes dominates the circle with a radius of 200 km around the society. Highest IC indicates the highest impact class in the circle. Actual historic irrigation data is from the Ethnographic Atlas.

3.3 Irrigation potential and modern irrigation

The evidence from premodern societies supports our conjecture that societies with a history of irrigation are mainly found in Irrigation Impact Class 5. We cannot conduct a similar test at the country level, since no consistent data on historical irrigation use exists.³¹ Instead, we compare our measure of irrigation potential to modern data on actual irrigation from AQUASTAT, a database maintained by FAO.

For each country, we compute the share of cultivated land that is irrigated, and regress the resulting variable on our measure of irrigation potential based on Impact Class 5. The coefficient on irrigation potential and the R^2 of the regression are reported in the top row of Table 2. Without any control variables, the coefficient is 0.3 and significant, implying that countries with *irrigation potential* = 1 on average have 30 percentage points more of their cultivated land under irrigation than countries with *irrigation potential* = 0. The correlation does not appear to be driven by one or more of the geographical and climatic factors underlying our measure of irrigation potential. On the contrary, the estimated coefficient on irrigation potential increases when we add control variables for absolute latitude, soil quality, average temperature, and average precipitation. The rise in the estimated coefficient reflects that the control variables explain some of the variation in irrigation outside Impact Class 5. For instance, latitude is known to be correlated with income, and richer countries are more likely to invest in irrigation systems in low impact areas.

We add the lower impact classes to our baseline measure of irrigation potential in the rows below. Consistent with the results from the Ethnographic Atlas, the estimated coefficient and the explanatory power drop successively, the broader measure we use. The probability of having irrigation, it seems, increases with the return to irrigation.

³¹The estimates for 1900 in Freydank & Siebert (2008) are a possible exception. See Appendix C.

Table 2. OLS regressions of actual current irrigation on irrigation potential

	(1)	(2)
Dependent variable: Actual current irrigation as a share of cultivated land		
	Estimated coefficient	R ²
Irrigation potential based on IC 5	0.336***	0.192
Irrigation potential based on IC 4-5	0.332***	0.181
Irrigation potential based on IC 3-5	0.265***	0.110
Irrigation potential based on IC 2-5	0.158*	0.039
Geographical controls	No	Yes
Observations (countries)	141	141

Notes: The measure of irrigation potential in row 1 is our baseline measure based on IC5 only. It measures the fraction of land suitable for agriculture where the gain from irrigation is larger than 100%. In row 2 the cut-off is 50%, in row 3 it is 20%, and in row 4 it is 1%. The dependent variable is actual irrigation in year 2000 as a fraction of cultivated land. Column (2) includes the following geographical controls: absolute latitude, avg precipitation, avg temperature, and soil quality, all described in Data Appendix A. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively.

Despite this correlation, there is a substantial amount of irrigation in the lower impact classes. The global area equipped for irrigation rose fivefold in the 20th century, and mainly in areas where irrigation has a modest impact on yields, but is nevertheless profitable due to cheap modern irrigation techniques.³² For instance, much of the irrigation in the United States and Europe is precautionary, and used only when an occasional drought hits. Without a substantial effect on annual yields, irrigation is unlikely to be a profitable target for rent-seeking. And even where irrigation is crucial to production, the scope for rent-seeking is likely to be smaller as water pumped from aquifers are harder to monopolize than water diverted from dams and canals. Moreover, the dramatic increase in the extent of irrigation in the 20th century is unlikely to have had any substantial effect on the quality of national institutions in countries which were already industrialized when irrigation was adopted.

³²Estimates from Freydanck & Siebert (2008). Areas equipped for irrigation are not necessarily using irrigation actively.

So the modern irrigation data are a sum of historical irrigation systems, which we expect to influence institutions, and the increase in irrigation of the modern sort, which is unlikely to have a similar effect. An OLS regression of institutions on modern irrigation data will by implication be a downward biased estimate of the effect of historical dependence on irrigation, and the bias is likely to be sizeable given the fivefold increase of irrigation in the 20th century. The problem cannot be solved by using irrigation potential as an instrument for actual modern irrigation. The increase in modern irrigation is inversely related to our measure of irrigation potential exactly because most modern irrigation systems were constructed in areas where they were not profitable without 20th century technology. This inverse relationship implies that irrigation potential is an invalid instrument for actual modern irrigation, and the instrumental variable (IV) estimates are consequently biased.³³

The reduced form estimates of institutions on irrigation potential do not suffer from the same bias, and we therefore use irrigation potential directly as explanatory variable in our main regressions.³⁴ We do, however, report IV estimates as robustness checks in Appendix C. We find a significant relationship between irrigation and institutions when we use IV estimation.

4 Empirical results: democracy

We use the *polity2* index from the Marshall *et al.* (2010) Polity IV database as our main measure of democracy at the country level.³⁵ The *polity2* index is widely used in quantitative studies of democracy. It ranges from -10 (hereditary monarchy) to 10 (consolidated democracy). Examples of countries with a score of 10 in the *polity2* index are the United States, United Kingdom, and Sweden. The only countries to score a -10 are Saudi Arabia and Oman, but Swaziland, North Korea, and Uzbekistan come close with a *polity2* score of -9.

Column (1) in Table 3 shows the relation between *irrigation potential* and the *polity2* index

³³See Appendix C for a formal statement of this bias.

³⁴Even without the mentioned bias, there would not be much additional information in the IV estimates. In the exactly identified setting, the IV estimates simply amount to a rescaling of the reduced form estimates. The sign on the coefficient for instrumented irrigation is the same as the sign of the coefficient on irrigation potential in the reduced form regression. And since the magnitudes of coefficients in both cases do not have a natural interpretation independent of the scaling of the variables, the rescaling is superfluous.

³⁵The data is available online from www.systemicpeace.org/polity/polity4.htm.

in 2010. The coefficient from a simple OLS regression is negative and significant, indicating that countries with higher irrigation potential are more autocratic.³⁶ Taken at face value, the estimate implies that a country with no irrigation potential will be 9.5 points more democratic on the 21 point *polity2* scale than a country with full irrigation potential.

We are interested in long-term effects, and using a single year of observation may therefore introduce noise in the *polity2* scores in countries with unstable regimes. We therefore follow Hariri (2012) and use the average of the *polity2* index over the post-Cold War period (1991-2010) as our main outcome variable in the empirical analysis below. As shown in column (2) of Table 3, the absolute size of the estimated coefficient is marginally larger and the standard errors marginally lower than when we use the 2010 data.

We compute the average of *polity2* over 1950-2010 ignoring missing observations. Changing the period does not alter the estimate on irrigation as shown in column (3). Exploiting the entire time-span available, column (4) shows that irrigation influences the *polity2* score average over the full period 1800-2010.³⁷ For robustness, column (5) shows that irrigation influences the *polity2* index in the early period, 1800-1950.

Dependent variable	(1) polity2	(2) polity2	(3) polity2	(4) polity2	(5) polity2	(6) freedom house
Irrigation potential (%)	-9.558*** (1.497)	-9.726*** (1.386)	-8.537*** (1.130)	-9.537*** (1.963)	-6.312*** (1.940)	2.599*** (0.393)
Observations	158	160	160	44	44	177
R-squared	0.216	0.227	0.187	0.217	0.085	0.155
Period	2010	1991-2010	1950-2010	1800-2010	1800-1950	1991-2010

Notes: OLS estimates. The dependent variable in columns (1)-(5) is averages of the *polity2* index. It measures how democratic political institutions are and ranges from -10 (least democratic) to 10 (most democratic). The dependent variable in column (6) is an average of civil liberties (ranges 1-7) and political rights (ranges 1-7) from Freedom House, where a higher score indicates a lower degree of freedom. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

Institutional quality is hard to measure, and no quantitative yard stick for democracy is perfect. We check the robustness of our results to the choice of democracy indicator by using

³⁶The effect goes through both subindices of the *polity2* index. The coefficient on irrigation potential in a regression with the democracy index substituted for the *polity2* index is -5.207. The similar coefficient for the autocracy subindex is 4.886. Both estimates are significant at the 1% level.

³⁷Countries were included in the average score if they had at least one data point in each of the periods 1800-1849, 1850-1899, 1900-1949, and 1950-2010.

an alternative measure of democracy: The average of the Civil Liberties and Political Rights ratings by Freedom House. Countries are categorized on a scale from 1 to 7 according to the amount of political rights and civil liberties they offer their citizens. A rating of 1 indicates the highest degree of freedom and 7 indicates the lowest. As expected, citizens living in areas with higher irrigation potential are less likely to enjoy civil liberties and political rights (Column 6 of Table 3). In the remainder of this paper, we use the *polity2* index as explanatory variable, but we obtain similar results using the Freedom House measure.

4.1 Baseline geographical control variables

Table 4, column (1) shows the relationship between the *polity2* index averaged over the period 1991-2010 and irrigation potential when continent dummies are included in the regression. Compared to column (2) of Table 3, the coefficient on irrigation potential decreases since Africa and Asia both have higher irrigation potential and are more autocratic than the average continent.

To check whether the link between democracy and irrigation potential is driven by spatial autocorrelation, we provide Conley (1999) standard errors in squared brackets. The Conley (1999) standard errors are similar to the ordinary robust standard errors, indicating that spatial autocorrelation is not a worry.

Following Hall & Jones (1999), the distance from the equator is widely used as a proxy for development or institutional quality in empirical studies. As shown in column (2), countries located further away from the equator are indeed more democratic, but the coefficient on irrigation potential is unchanged and remains highly significant.

Table 4. Democracy on irrigation potential controlling for geography

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Polity2 index 1991-2010								
Irrigation potential (%)	-6.369*** (1.534) [1.574]	-5.898** (2.534) [2.903]		-7.123** (2.857) [2.915]	-5.037*** (1.632) [1.629]	-6.454*** (1.535) [1.570]	-4.723* (2.553) [2.534]	-6.854*** (2.438)
Absolute latitude		0.115* (0.066)					0.121* (0.065)	0.149* (0.082)
Precipitation		1.382 (1.140)	6.737*** (2.301)	-0.733 (3.549)			1.471 (1.114)	1.856 (1.358)
Temperature		0.012 (0.125)					0.043 (0.123)	0.032 (0.121)
Soil constraints (%)		-5.474 (4.730)					-4.977 (4.811)	-2.551 (5.793)
Squared precipitation			-2.131** (0.914)	0.111 (1.212)				
Oil (1000 barrels/day/cap)					-5.703*** (1.833)		-5.230*** (1.590)	-2.867 (2.814)
Land within 100 km of navigable rivers %						-2.843 (1.988)	-3.424 (2.106)	0.443 (2.768)
Observations	156	156	156	156	156	156	156	156
R-squared	0.486	0.512	0.454	0.487	0.507	0.491	0.535	
Estimation	OLS	OLS	OLS	OLS	OLS	OLS	OLS	Median
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Altonji test		12.5		-9.4	3.8	-75.8	2.9	-14.1

Notes: OLS estimates in columns (1)-(7), Median regression estimates in column (8). The dependent variable is the polity2 index averaged 1991-2010. The remaining variables are described in Data Appendix A. The Altonji test statistic takes column (1) as the restricted model. All regressions include a constant. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively, based on the robust standard errors reported in parentheses. Conley (1999) standard errors in brackets (cut-off = 500 km).

Irrigation potential is based on numerous geographical and climatic variables. To check whether it is one of the components of the irrigation potential variable, and not the variable itself, that is correlated with the *polity2* index, we include the most important components in our regression. These are average annual temperature, average annual precipitation and soil quality. We control for these variables column (2). None of them are significant, and their inclusion has negligible impact on the irrigation potential coefficient.³⁸

The relationship between irrigation potential and *polity2* estimated in column (2) is depicted in the AV-plot in Figure 2. There is a visible negative relationship, but a number of outliers are also visible. The unique histories of Israel and Cuba have, for instance, provided them with institutions that deviates from the norms in their regions. Mongolia is likewise a visible outlier. It has a high irrigation potential, but Mongolia's agriculture relies on nomadic animal husbandry rather than irrigation. Such outliers are, however, not what drives our results. On the contrary, when we estimate the regression in column (3) by median regression

³⁸Including the variables one by one produces similar results. Additional controls related to the calculation of irrigation potential are added in Appendix B.

robust to outliers, we get a coefficient on irrigation potential of -10.118 compared to -5.898 in the OLS case. The same is true for all the other empirical results we provide in this paper: outliers reduce the coefficient on irrigation potential in absolute size, and the OLS estimates are in this regard conservative.

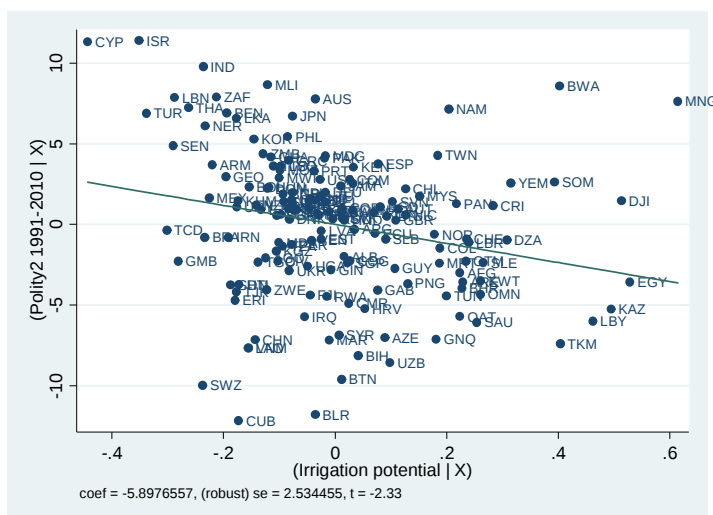


Figure 2. AV plot of the polity2 index on irrigation potential (Table 4, column 2)

4.2 Additional geographical control variables

Cereals are usually associated with good institutional outcomes and plantation crops with poor. As discussed in the introduction, Haber (2012) shows that modern democracies are clustered in areas with moderate rainfall, which he argues proxy for the climatic suitability for growing rainfed cereals. Areas with more rain are suitable for plantation crops, and areas with less rain for irrigated agriculture. In our regressions, we capture the nonlinear relationship between rainfall and democracy by adding precipitation and precipitation squared as control variables in Table 4. Column (3) shows that the nonlinear relationship exists when irrigation potential is excluded from the regression. But when we include irrigation potential in Column (4), both rainfall terms become insignificant, individually and jointly.³⁹ The results of Haber (2012) thus appear to be driven by the correlation with irrigation.⁴⁰

³⁹Confirmed by an F-test with a p-value of 0.897.

⁴⁰Easterly (2007) provides an empirical study of the plantation crops vs. cereals theory of institutions. He uses the agro-climatic suitability of wheat relative to sugar as a proxy of dependence on cereals rather than plantation crops. We include this measure as a control variable in Appendix B, as well as a more general measure of dependence on cereals relative to plantation crops. The estimated effect of irrigation is robust to these variables.

Natural resource endowments other than crops are potentially important confounders. Many countries in the Middle East, for instance, both depend on irrigation and oil production. We add oil production per capita as a control variable in our regression in Column (5) of Table 4. Consistent with the findings of Ross (2001, 2012), Isham *et al.* (2005), Williams (2011) and Bulte *et al.* (2005), oil wealth appears to support authoritarian regimes. The effect is, however, distinct from the effect of irrigation. The coefficient on irrigation potential is still negative and significant at the 1%-level when oil production is included in the regression.⁴¹

Many of the ancient irrigation based societies relied on water from major rivers, such as the Nile, Euphrates, Indus and Ganges. The rivers also facilitated trade and easy transportation for government officials and armies. We therefore add the fraction of land within 100 km of navigable rivers as a control variable in Column (6). The coefficient on irrigation potential is unchanged. In the appendix, we show that using smaller rivers and coasts yields similar results.

All geographical control variables are included simultaneously in Column (7). The main result pertains: Countries with higher irrigation potential are more autocratic. The significance level falls to 10 percent due to a combination of the large number of insignificant control variables and outliers. In Column (8) we use median regression robust to outliers, and find a strong effect of irrigation potential on democracy.

The coefficient on *irrigation potential* lies between -5 and -6 in most of the specifications in Table 4. So a country with no irrigation potential is 5-6 points more democracy on the *polity2* scale than a country with full irrigation potential. 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.

We have tested the robustness of our results to a wide range of additional geographical control variables. These include: malaria ecology, land within 100 km of the coast, land within 100 km of the coast or navigable rivers, land within 100 km of large rivers, land within 100 km of all rivers, land within the tropics, average or variance of altitude, terrain ruggedness, total area, a dummy for whether a country is landlocked or not, variation in rainfall, soil salination, mean and variance of agricultural suitability, land suitable for agriculture as a share of total area, growing season days, squared latitude, suitability of cereals as opposed to plantation crops, mineral rents, and a diamond dummy. The results are reported in Appendix B, Table B2. The estimated coefficient on irrigation potential is robust to adding these variables to the

⁴¹We control for mineral rents as a share of GDP and a dummy for diamond production in Appendix B.

regression.

While we have controlled for a large number of observable geographical characteristics, there may still be omitted confounders. We report the Altonji *et al.* (2005) statistic for the importance of selection on unobservables relative to observables at the bottom of Table 4.⁴² A test statistic greater than one implies that to reduce the estimated coefficient on irrigation potential to zero, unobservables should explain more of the covariance between irrigation potential and the polity2-index than the included control variables (continents excluded). Given that the Altonji *et al.* (2005) statistic is larger than 2 in all specifications, we are relatively confident that our results are not driven by unobserved geographical variation.

4.3 Development and colonization

In Table 5, we check the robustness of our results to possible confounders related to historical and present development. We have fewer observations than in Table 4 as the control variables we include here are not available for as many countries as the geographical variables.

Lipset (1959) famously hypothesized that democracy is a consequence of economic modernization. If the theory is correct and if irrigation is correlated with economic development, the observed effect of irrigation on institutional quality could work through modernization. For instance, a high irrigation potential could slow democratization if irrigated societies specialized in agricultural production and failed to develop modern industries.⁴³

As a first step to check whether that is the case, Column (2) of Table 5 includes the logarithm of real GDP per capita in year 2000 from Penn World Tables. As expected, richer countries are more democratic.⁴⁴ But the effect does not seem to work through irrigation, since the estimated coefficient on irrigation potential is unchanged. In Column (3), we include the number of years since each country passed through the Neolithic transition, *i.e.*, when the population started farming rather than hunting. In Column (4) we include the State Antiquity Index, which captures the cumulated number of years a state has been present within modern-day country borders.⁴⁵ Both variables have been shown to be correlated with contemporary

⁴²We use the specific version of the test suggested by Nunn & Wantchekon (2011).

⁴³Matsuyama (1992), Galor & Mountford (2006, 2008), and Williamson (2011), among others, argue that such specialization in agricultural production might explain the unequal global distribution of income today.

⁴⁴Note, however, that this result is potentially biased as GDP is likely to be endogenous.

⁴⁵Years since the Neolithic Transitions is from Putterman & Trainor (2006), and the State Antiquity Index is from Bocksette & Putterman (2007). The results are similar when we use the Putterman (2008) migration-adjusted years since the Neolithic Revolution.

as well as historical measures of economic development.⁴⁶ But both are insignificant in our regression.

Column (5) includes population density in 1500 AD from MacEvedy & Jones (1978). Population density is a standard measure of economic development in Malthusian economies where higher agricultural productivity translated into higher fertility and/or lower mortality rather than higher living standards.⁴⁷ The coefficient on population density is positive, indicating that areas which were more developed historically are more democratic today. At first, this result seems at odds with the reversal-of-fortune argument put forward by Acemoglu *et al.* (2002). They argue that densely populated regions colonized by European powers received fewer European settlers, and that it was the European settlers that brought democracy to the colonies. However, the estimated coefficient on population density is mainly driven by Europe and countries that were never colonized by Europeans.

Table 5. Democracy on irrigation potential controlling for development and colonization

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable: Polity2 index 1991-2010										
Irrigation potential (%)	-5.609*** (1.904)	-6.673*** (2.062)	-4.751** (2.213)	-5.487*** (2.076)	-4.785** (1.872)	-5.562*** (1.864)	-5.718*** (1.908)	-5.641*** (1.936)	-4.332* (2.457)	-5.597** (2.218)
(log) Real GDP/cap, 2000		1.329*** (0.468)							1.113** (0.541)	0.527 (0.444)
Years since Neolithic			-0.458 (0.393)						-0.480 (0.401)	-0.533 (0.373)
State Antiquity Index				-0.000 (0.001)					-0.001 (0.001)	
Pop density, 1500					0.131*** (0.046)				0.147*** (0.056)	0.145*** (0.047)
Colony dummy						0.269 (1.832)			-0.434 (1.805)	-2.096 (1.518)
European language (%)							2.615*** (0.899)		0.213 (0.885)	1.110 (0.997)
Local headman (Ethno Atlas)								0.430 (1.136)	-0.629 (1.166)	
Observations	128	128	128	128	128	128	128	128	128	148
R-squared	0.476	0.514	0.486	0.476	0.503	0.476	0.485	0.476	0.551	0.559
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index averaged over the period 1991-2010. The remaining variables are described in Data Appendix A. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

A large body of research has demonstrated the lasting effect of colonization on institutions.⁴⁸

⁴⁶ *E.g.*, Diamond (1997), Bockstette *et al.* (2002), Hibbs & Olsson (2004) Hariri (2012), and Olsson & Paik (2013).

⁴⁷ See, *e.g.*, Ashraf & Galor (2011).

⁴⁸ *E.g.*, Acemoglu *et al.* (2001, 2002), Engerman & Sokoloff (2000), Iyer & Banerjee (2005), Nunn (2007), Feyrer & Sacerdote (2009), Olsson (2009), Dell (2010), and Hariri (2012).

We address this potential confounder in two ways. In Table 5, by adding control variables for colonization, and in Table 6 below by splitting the sample. In Column (6) of Table 5 we include a dummy which equals one if the country was ever colonized. Colonization does by itself not explain variation in present-day democracy in addition to the variation explained by irrigation potential. But, as Column (7) shows, the number of European settlers, as proxied by the fraction of the population that speaks a European language, does. The impact of irrigation potential on democracy is, however, not affected by adding this control variable.⁴⁹

Lastly, we add a control variable for pre-colonial institutions in column (8) proposed by Giuliano & Nunn (2013). The variable is based on observations from the Ethnographic Atlas, and it measures whether local village headmen in a country were chosen by election and/or informal consensus rather than by less democratic succession rules. The variable is insignificant, and does not have any impact on the coefficient of irrigation potential.⁵⁰

All variables are included simultaneously in Column (9). The coefficient on irrigation potential is reduced somewhat compared to Column (1), but not significantly so. The State Antiquity Index and historic democracy have fewer observations than the other variables. And since they are both insignificant, we exclude them in Column (10) to increase the number of observations. As a result, both the size and the significance level of the irrigation potential coefficient increases.⁵¹

We now return to a more thorough investigation of colonization. In Table 6, we split the sample into a sub-sample of the 64 countries that were never a colony (columns 1-3) and a sub-sample of the 96 countries that were colonized at some point in time (columns 4-6). The coefficient on irrigation potential retains its sign and significance in both subsamples. However, the impact and explanatory power of irrigation is stronger in the sample of countries that were never colonized. Our interpretation of this result is that European colonialism dilutes the effect of irrigation by creating additional variance in institutions unrelated to irrigation. This interpretation is consistent with the institutional legacy of colonization demonstrated empirically by the studies cited in Section 2.3.

Acemoglu *et al.* (2001, 2002) argue that the disease environment was crucial for the types of institutions set up by Europeans. Humid areas are more dangerous in this respect, and

⁴⁹Using instead a measure of fraction of the population of European descent produces similar results. In Appendix B, we also add control variables for countries legal systems. Legal systems were often part of the package of institutions implemented by colonizers in their colonies.

⁵⁰Continent dummies and not irrigation potential turns the coefficient on this variable insignificant. This point is also made by Bentzen *et al.* (2015).

⁵¹The coefficient on irrigation potential increases in all columns when the sample is increased to 148 countries.

the disease environment is therefore inversely correlated with irrigation potential. To test this possible confounder in the colony sub-sample, we include malaria ecology in the last column of Table 6.⁵² When irrigation is accounted for, we do not find support for the hypothesis that the disease environment has an impact on current institutions in former colonies.

Table 6. Democracy on irrigation potential in non-colonies vs colonies						
Sample	(1)	(2)	(3)	(4)	(5)	(6)
	All	Never colonized All	Non-Europe	All	Former colonies All	All
Dependent variable: Polity2 index 1991-2010						
Irrigation potential (%)	-15.436*** (2.859)	-11.364*** (3.549)	-11.684*** (3.698)	-6.051*** (1.576)	-3.441** (1.508)	-3.352* (1.716)
Malaria ecology index						0.012 (0.080)
Observations	64	64	29	96	96	96
R-squared	0.485	0.560	0.356	0.109	0.423	0.423
Continent dummies	No	Yes	Yes	No	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index averaged over the period 1991-2010. The remaining variables are described in Data Appendix A. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

4.4 Religion

People with the same religious beliefs often share cultural values, and these values may affect political institutions and development. Weber (1930) famously linked the rise of capitalism to Protestantism. More recently, Bruce (2004) describes how Protestant culture can be conducive to democracy. Most of the contemporary debate about religion and democracy is, however, centered on Islam.⁵³ Muslim countries are, on average, less democratic than other countries, and some observers argue that the tenets of Islam are inherently incompatible with democracy.

We include the population share of adherents to each of the major world religions in Table 7. When included individually, the correlations between each of these measures and institutions are as suggested by the literature: Muslim countries are less democratic than the average country, and Protestant countries more democratic. The coefficients on Catholics and Buddhists are insignificant. The coefficient on irrigation potential drops somewhat when the fraction of Muslims are included, and the significance level decreases to 10 percent.⁵⁴

⁵²Acemoglu *et al.* (2001, 2002) use settler mortality and not malaria ecology as a measure of the disease environment. Data on settler mortality is, however, only available for a small sample of colonies. Moreover, the coefficient on settler mortality is insignificant in our regressions.

⁵³See *e.g.*, Bellin (2004), Huntington (1993), Kedourie (1992), and Hariri (2015).

⁵⁴Again, the coefficient on irrigation potential remains large and significant at the 5 percent level when we use median regression robust to outliers.

These results may, however, be biased since the spread of religion, especially Islam, could be endogenous to irrigation potential. Michalopoulos *et al.* (2012) demonstrate that Islam spread from the Arab Peninsula along major trade routes. Most of the trade routes ran along an East-West axis, thus spreading the religion into regions with a similar climate. Furthermore, Michalopoulos *et al.* (2012) show that Islam was more likely to take hold in areas with large variation in soil fertility. They explain the latter by noting that variation in soil quality was a source of income inequalities, and that Islam’s redistributive aims had more appeal in areas with large inequality. Variation in soil quality is extreme in areas where desert intersects with irrigated fields, and, as we show later in this paper, land ownership is more unequal in irrigated areas. So an alternative interpretation of the results of Michalopoulos *et al.* (2012) is that Islam spread to societies with agriculture based on irrigation, because these societies were more unequal than elsewhere.

In a related paper, Chaney (2012) uses desert ecology as an instrumental variable for Arab conquest. Arab armies depended on camels, and their ability to protect power was therefore larger close to desert terrain. Irrigation is often found close to such terrain, and Arab conquest and the spread of Islam could consequently be determined by geographical factors related to irrigation potential for military reasons.

The dynamics of the spread of Islam means that irrigation potential and the share of Muslims in the population are highly correlated at the country level ($\rho = 0.65$). Moreover, much of the variation in irrigation potential in our data is within the group of countries which at the present have Muslim majorities. This makes it hard to disentangle the effect of Islam from the effect of irrigation potential in the regressions reported in Table 7. We therefore turn to subnational evidence in the next subsection. To preview the results, we demonstrate that individuals living in areas with high irrigation potential have less favorable views on democracy even when country fixed-effects and the religion of the respondent are taken into account. In fact, Muslims appear to have more favorable views on democracy than followers of other religions. So the negative relationship between Islam and the *polity2*-index in Table 7 does not appear to be explained by Muslims being culturally opposed to democratic institutions. This is consistent with the fact that relatively few of the Muslim countries in our sample are theocracies. Rather, Islamic outfits such as the Muslim Brotherhood have often acted as the main opposition to secular oppressive regimes, such as the Ba’athists in Iraq and Syria, and the military dictatorship in Egypt. Likewise, we demonstrate in Section 5 that societies with a high irrigation potential are more unequal in terms of land ownership no matter their

religious adherence. Our interpretation of the results in Table 7 is therefore that Islam is more widespread in regions where high irrigation potential supports oppressive regimes.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable: Polity2 index 1991-2010						
Irrigation potential (%)	-5.785*** (1.543)	-3.406* (2.057)	-5.505*** (1.574)	-5.719*** (1.563)	-6.020*** (1.668)	-3.648* (2.107)
Muslims 2000 (%)		-3.704* (1.996)				-4.009* (2.414)
Protestants 2000 (%)			3.750** (1.749)			1.899 (2.345)
Catholics 2000 (%)				0.565 (1.318)		-0.321 (1.854)
Buddhists 2000 (%)					-1.497 (3.911)	-3.458 (4.192)
Observations	158	158	158	158	158	158
R-squared	0.475	0.496	0.482	0.475	0.476	0.503
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index averaged over the period 1991-2010. The remaining variables are described in Data Appendix A. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

4.5 Subnational evidence: attitudes towards democracy

While we have controlled for a wide range of possible confounders, we cannot rule out that one or more unobserved variables correlate with both irrigation potential and democracy. Many possible unobservables are likely to correlate at the national level, so we now turn to sub-national data which allow us to include country fixed-effects in our empirical analysis. Comprehensive sub-national data on actual institutions do, unfortunately, not exist. Instead, we use survey data on individuals' views on democracy taken from The World Values Survey and the European Values Study.

Survey participants are asked two questions about democracy. The first is whether they feel a democratic political system is very good, fairly good, fairly bad or very bad.⁵⁵ From the answers we create an index where the value 4 indicates that the response is "very good", 3 if the response is "fairly good", and so on. The second question is whether respondents agree with the following statement: "Democracy may have problems but it is better than any other form of government". Respondents can strongly disagree (index value 1), disagree (2), agree (3), and strongly agree (4).⁵⁶ We label the resulting variables *demo_good* and *demo_better*.

⁵⁵Question e117 in the pooled WVS / EVS.

⁵⁶Question e123 in the pooled WVS / EVS. We have transformed the original variable such that higher values indicate a more favorable view on democracy.

The answers to these questions are only weakly correlated with national measures of actual democracy, as democracy means different things in different countries.⁵⁷ We remove the country specific interpretations in our analysis by including country fixed effects. We conjecture that the remaining variance in views of democracy are correlated with institutions at the regional level. People are likely to view democracy less favorably in regions where democracy functions less well. In nominal democracies, for instance, trust in democracy will be lower if people feel that the elite control the democratic institutions for their own benefit. In authoritarian regimes, more powerful local elites will be better able to conduct propaganda against democracy, and thereby affect the perceptions of the masses.

We pool all available waves (1981-2009) of the World Values Survey and European Values Study in our empirical analysis. The surveys divide countries into multiple subnational districts, and we match the survey data in each district to district-level irrigation.⁵⁸ This enables us to estimate regressions of the form:

$$democracy_{i,d,c,t} = \alpha_0 + \alpha_1 irrigation_{d,c} + a_c + \lambda_t + X'_{i,d,c,t}\beta + W'_{d,c,t}\delta + u_{i,d,c,t} \quad (3)$$

for individual i interviewed in subnational district d in country c at time t . *democracy* measures individuals' expressed values for democracy, *irrigation* is irrigation potential measured at the subnational district level. a_c is a country-fixed effects and λ_t is a time fixed-effect. $X_{i,d,c,t}$ is a vector of individual controls, and $W_{d,c,t}$ a vector of geographical controls at the district level. We cluster the standard errors at the district level.

Table 8 shows the impact of irrigation potential on *demo_good* and *demo_better*. All columns control for country- and time fixed effects, age, gender, agricultural occupation, and income- and educational attainment fixed effects. Columns (2) and (5) add the basic geographical controls at the subnational district level: absolute latitude, precipitation, temperature, and soil constraints. In Column (3) and (6), we control for whether a respondent is Muslim.

The results in all columns of Table 8 show that individuals value democracy less when residing in subnational districts with higher irrigation potential. In all regressions, the coefficient on irrigation potential is significant at the 5 percent level, except in Column (3) where it is significant at the 10 percent level.

A priori, a relatively weak level of significance is to be expected. Views of democracy as a principle is a noisy indicator for actual institutional quality. Moreover, we remove a lot of

⁵⁷Coppedge (2012).

⁵⁸The methodology is described in Bentzen (2015).

variation in institutions by including country fixed effects. In this light, it is striking that the relationship between irrigation and institutions persists at the sub-national level.

The coefficient on the dummy indicating whether a respondent is Muslim is positive, and, in Column (3), significant. Surprisingly, Islam is associated with *more* favorable views on democracy for a given level of national democracy. The point estimate on irrigation potential is statistically unchanged when the Muslim dummy is included. If anything, it increases in numerical value.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable		demo_good			demo_better	
Irrigation potential (%)	-0.059** (0.028)	-0.059** (0.030)	-0.057* (0.033)	-0.074** (0.032)	-0.086** (0.036)	-0.099** (0.039)
Muslim			0.046*** (0.017)			0.020 (0.048)
Observations	96,315	95,444	74,854	62,342	61,675	47,927
R-squared	0.104	0.105	0.104	0.121	0.122	0.129
Country FE	Y	Y	Y	Y	Y	Y
Individual controls	Y	Y	Y	Y	Y	Y
Geo controls	N	Y	Y	N	Y	Y
Number countries	70	70	69	52	52	51
Number regions	749	743	725	485	481	454

Notes. OLS estimates. The unit of analysis is individuals. demo_good is the answer to whether the respondent thinks that a democratic system is very bad (scores 1), fairly bad (2), fairly good (3), or very good (4). demo_better is the answer to whether the respondent disagrees strongly (scores 1), disagrees (2), agrees (3), or strongly agrees (4) with the claim that democracy may have problems, but is the best political system. The individual controls are year fixed effects, age, gender, a dummy for agricultural worker, and 10 income and 8 education fixed effects. Geo controls refer to district level controls for absolute latitude, precipitation, temperature, and soil constraints. Standard errors, clustered at the district level, are reported in parentheses. ***, **, and * indicate significance at the 1, 5, and 10% level.

5 Land inequality

Our results so far confirm that irrigation based societies are more likely to be autocracies today. In Section 2, we argued that this link arose from irrigation granting landed elites a monopoly over water in arid areas, and that this monopoly fostered a concentration of land ownership in the hands of the elite. In this section we provide empirical evidence for this mechanism.

5.1 Evidence from The Ethnographic Atlas

Our first piece of evidence comes from The Ethnographic Atlas.⁵⁹ We use the Atlas to construct a dummy variable, *elite*, which equals 1 for societies "...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 remove societies of hunters and gatherers from the sample, as irrigation is only relevant for societies whose livelihood depends on agriculture. That leaves us with a sample of 770 societies, of which 45 societies are coded as *elite* = 1.⁶⁰ None of the non-agricultural societies are elite societies.

To check whether the historical inequality captured by the *elite* variable has a bearing on contemporary institutions, we average the variable across ethnographic societies within the borders of modern countries and compare the results to the *polity2* index. The correlation, shown in Table 9, is -0.23 and significant, so areas which historically had strong elites are more likely to be autocratic today.

The *elite* dummy variable is derived from the Atlas' categorization of social stratification. Elite stratification is one of five possibilities: Complex stratification, hereditary aristocracy, elite stratification, wealth distinctions, and absence among free men. The five forms of social stratification are not mutually exclusive. A society with hereditary aristocracy can, for example, also have elite stratification.

Table 9 also shows the correlation between the *polity2*-index and the four other forms of social stratification. Elite stratification has a numerically higher correlation with the *polity2* index than the other four forms of stratification, and is the best predictor of autocracy today. The only other significant coefficient is the one for complex stratification. But complex stratification is vaguely defined, and no clear conclusions can be drawn from this correlation.

Table 9. Simple correlations between polity2 and stratification	
	<i>polity2</i>
Stratification based on:	
- Absence among free men	0.08
- Wealth distinctions	-0.13
- Elite control of resources	-0.23**
- Hereditary aristocracy	-0.11
- Complex (social classes)	0.19**
Observations (countries)	115

⁵⁹Murdock (1967). See also Section 3.2.

⁶⁰There are 826 countries in our sample with agriculture, but some of them are located on small islands for which we do not have data on irrigation potential. These are excluded from the sample. None of the excluded societies have elite stratification.

Notes: Simple correlations between the polity2 index and the five stratification groups across 115 countries. The stratification measures are dummies averaged within present-day borders. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

For each society in the sample, we calculate *irrigation potential* and all the geographical control variables as averages within a 200 km radius of the society centre. We then regress our *elite* dummy on the irrigation potential of a society. The results are reported in Table 10.

In all specifications, we control for the century in which a society is observed, and for language group fixed effects. A shared language is an indicator of common cultural, religious, and historical background, and we thereby remove variation in elite stratification caused by such possible confounders. Without any other control variables, the estimated coefficient on irrigation potential is 0.362 and significant at the 1%-level. The regression is a linear probability model, and the result implies that the probability of being ruled by an elite is 36 percent higher for societies with irrigation compared to societies with rainfed agriculture. We get similar results when we include our baseline geographical controls from Section 4, shown in column (2).

A potential omitted variable is development: elite stratification may simply be absent in primitive societies. We add three control variables from the Ethnographic Atlas one-by-one in columns (3)-(5) to control for this possibility: the density of the settlement, the intensity of agriculture, and a dummy for whether a society was a part of a state.⁶¹ None of the variables are significant, and our main result does not appear to be driven by variation in development.

In Column (6), we control for whether the local headman (if any) was appointed by election or informal consensus rather than less democratic procedures. While earlier studies have shown that this variable is correlated with democracy today, it is uncorrelated with historical land inequality as measured by our elite dummy.⁶² Historical land inequality and proto-democratic institutions appear to be to distinct determinants of present day democracy.

In Column (7), we include all four control variables simultaneously. There are fewer observations of elected headmen in the Ethnographic Atlas than of the other control variables, and the sample size therefore drops. In Column (8), we include all control variables but the appointment of the local headman (which is insignificant) to increase the sample size. The coefficient on irrigation potential is unchanged in both cases, indicating that there is a robust relationship between irrigation and land inequality across premodern societies.

⁶¹The dummy for part of a state corresponds to the centralization variable in Gennaioli & Rainer (2007).

⁶²See Giuliano & Nunn (2013).

Table 10. Elite stratification on irrigation potential								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable: Elite stratification								
Irrigation potential (%)	0.362*** (0.098)	0.324*** (0.089)	0.357*** (0.080)	0.356*** (0.098)	0.363*** (0.100)	0.362*** (0.097)	0.319*** (0.078)	0.313*** (0.069)
Settlement density			-0.003 (0.013)				-0.005 (0.015)	-0.008 (0.016)
Agricultural intensity				0.016 (0.012)			0.019 (0.017)	0.004 (0.012)
Part of state					0.025 (0.017)		0.023 (0.020)	0.019 (0.015)
Elected headman						0.002 (0.020)	-0.004 (0.023)	
Observations	569	569	569	569	569	569	569	750
R-squared	0.231	0.239	0.232	0.235	0.234	0.231	0.248	0.255
55 language dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Century fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic controls	No	Yes	No	No	No	No	Yes	Yes

Notes: OLS estimates. The dependent variable, elite, is a dummy variable equal to one if the society is ruled by an elite which bases its power on control of a natural resource. Geographic controls include avg temperature, avg precipitation, soil quality, and absolute latitude. All geographical variables are averaged within a radius of 200 km from the society centre. The control variables are described in Data Appendix A. ***, **, and * indicate significance at the 1, 5, and 10% level. All regressions include a constant. Robust standard errors clustered at the language-group level in parentheses.

5.2 Cross-country evidence

We use historical Gini-coefficients for the size of land holdings compiled by Frankema (2009) to test the link between irrigation and land inequality at the national level. The Gini coefficients measure inequality of access to land, rather than inequality of ownership. A sharecropper, for instance, has access to land he does not own. The Frankema (2009) Gini coefficients are therefore lower bounds for true inequality of land ownership.

The Frankema (2009) data set spans 111 countries, of which 104 has observations of the polity2-index. Most countries are observed more than once. Land inequality today is of little consequence to political institutions in modern economies where the bulk of the labour force works outside agriculture, so we use the earliest year available for each country to get the most precise measure of historical inequality. The earliest observation is the United States in 1880, but most countries are not observed until the middle of the 20th century.

We regress the Gini coefficients on irrigation potential and report the results in Column (1) of Table 11, Panel A. Countries with a high irrigation potential are significantly more unequal in terms of land holdings than other countries. A country with an irrigation potential 1 (the maximum) will, according to our estimates, have a land Gini that is 0.2 higher than a country

with no scope for irrigation. The Gini coefficients are bounded between zero and one, so it is a sizable effect.

As mentioned the Ginis are noisy indicators of true land inequality since they are based on land holdings rather than ownership. Furthermore, it does not take into account the landless farm workers or differences in soil quality. Some of the variation in the size of holdings may, for example, reflect variation in soil quality, as farms in infertile areas are more likely to employ extensive production methods. We control for variation in soil suitability for agriculture in our regressions in Column (2) of Table 11, Panel A to take this possibility into account. We also include decade dummies to remove potential variance stemming from differences in the year of observation. The coefficient on irrigation potential is unchanged.

In Column (3), we include all control variables from our cross country analysis in Section 4 simultaneously. Even with these 15 additional control variables, irrigation potential is still a highly significant predictor of land inequality.

5.3 A test of the inequality channel

Irrigation potential appears to be a strong predictor of historical land inequality as measured by the Frankema (2009) Gini coefficients. The Ginis, in turn, are negatively correlated with the polity2-index: societies that were more unequal historically are less likely to be democracies today. To rule out that the simple correlation is driven by endogeneity, we use irrigation potential as an instrument for land inequality. We report the second stage IV-estimates in Panel B of Table 11. The first stage estimates are reported in the corresponding columns of Panel A.

As shown in columns (1) - (3), irrigation potential is a strong instrument for land inequality, and instrumented land inequality has a large and highly significant negative effect on democracy.⁶³ This result is consistent with the idea that irrigation concentrates land ownership in the hands of an elite with little taste for democracy. The results holds when all control variables from the previous sections are included. Yet, we cannot rule out that irrigation potential determines both historical land inequality and present-day democracy through a third variable. Countries without irrigation may, for instance, have been more democratic already before land

⁶³With no control variables, the estimated effect of land inequality on the polity2-index increases in magnitude from -8 to -40 when IV estimation is used rather than OLS. The increase is consistent with the Frankema (2009) Gini coefficients being relatively crude proxies for true land inequalities. Some of the increase may also reflect endogeneity of land inequality.

inequality was first measured. The correlation we observe between land inequality and present democracy would then reflect that democracy is persistent, and that democratic countries are more likely to undertake land reform.

The fact that we generally observe land inequality before the big waves of land reforms in the 1960s and 1970s makes that possibility seem less likely, but we need to test it formally. To this end, we use an additional instrument for land inequality: the suitability of cereals relative to the suitability of plantation crops.⁶⁴ By having two instruments, we are able to test the exclusion restrictions of our instruments by a Hansen overidentification test. The Hansen test has low power, however, especially since the cereal-plantation crops suitability ratio turns out to be a relatively weak instrument for land inequality. Rather comforting, when the suitability ratio is used as the sole instrument, an Anderson-Rubin p-value of 0.047 confirms that an increased land Gini is detrimental to democracy (not shown).

We report the IV estimates with two instruments and the results of the Hansen overidentification test in columns (4) - (6) of Table 11. The null of the overidentification test is that the exclusion restrictions are not violated, *i.e.*, that the instruments do not affect democracy through other channels than land inequality. The test accepts the null with a p-value of 0.463 in column (4), where no control variables are included. The p-value increases to 0.667 when we control for variance in agricultural suitability and decade fixed effects. The endogenous control variables, such as GDP per capita and population in 1500 CE, reduce the p-value of the overidentification test to 0.199 when the full set of control variables is added to the regression in column (6). The p-value is 0.657 when only the exogenous baseline geographical control variables are included (not shown in the table).

Taken at face value, these test results indicate that irrigation potential *only* influences democracy through land inequality. The low power of the test makes this conclusion too strong. But the results are consistent with our hypothesis that elite rule, proxied by land inequality, is an important channel through which irrigation has an impact on present day institutions.⁶⁵

⁶⁴The instrument is the log of $\frac{1 + \text{land suitable for cereals} / \text{land suitable for agriculture}}{1 + \text{land suitable for plantation crops} / \text{land suitable for agriculture}}$. Cereals are buckwheat, maize, millet, oat, rhye, sorghum, and wheat. Plantation crops are banana, cocoa, coffee, sugar, and tea. This variable is a generalization of the Easterly (2007) measure of the wheat-sugar suitability ratio, which he uses as an instrument for inequality. Sugar is mostly relevant in the Americas, and the Easterly measure is therefore a weaker instrument than the generalization we use here.

⁶⁵We reach the same conclusion if we use the alternative test of the exclusion restriction on irrigation potential proposed by Acemoglu *et al.* (2002). In this test, the cereal-plantation crop suitability ratio is the only excluded instrument in the regression, and irrigation potential is included as a control. The coefficient on irrigation potential is in that case insignificant and slightly positive in the second stage, indicating that

Table 11. IV regression of democracy on land inequality						
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: First stage						
Dependent variable: Land Gini						
Irrigation potential (%)	0.193*** (0.040)	0.187*** (0.047)	0.278*** (0.087)	0.206*** (0.039)	0.202*** (0.049)	0.234** (0.095)
(log) Area with cereal / plantation crops				-0.062 (0.048)	-0.076 (0.058)	-0.053 (0.079)
R-squared	0.398	0.505	0.618	0.409	0.517	0.616
Panel B: Second stage						
Dependent variable: Polity2 index 1991-2010						
Land Gini	-41.914*** (9.792)	-48.347*** (10.948)	-29.967*** (11.519)	-46.595*** (9.170)	-51.284*** (11.594)	-42.639*** (15.794)
Kleibergen Paap F	23.05	16.14	10.17	14.26	8.514	4.390
Anderson-Rubin p	0.000	0.000	0.001	0.000	0.000	0.000
Hansen J p-value				0.463	0.667	0.199
Observations	102	102	102	102	102	102
Continents	Yes	Yes	Yes	Yes	Yes	Yes
Variance agr suitability	No	Yes	Yes	No	Yes	Yes
Decade fixed effects	No	Yes	Yes	No	Yes	Yes
Full set of controls	No	No	Yes	No	No	Yes

Notes: IV estimates of democracy on land inequality, where land inequality is instrumented with irrigation potential in columns (1) - (3) and with irrigation potential and the ratio between the suitability for cereal versus plantation crops in columns (4) - (6). Panel A shows the first stage results and panel B the second stage results. The full set of controls is average precipitation, average temperature, soil quality, absolute latitude, land within 100 km of navigable rivers, oil share, real GDP per capita, years since Neolithic Revolution, population density year 1500, colony dummy, European language share, Muslim share, Protestants share, Catholics share, and Buddhists share. See Data Appendix A for a description of these variables.

6 Conclusion

We have tested the theory that societies with a history of irrigated agriculture have developed more autocratic institutions than societies with a history of rainfed agriculture. Such a link has been hypothesized by many prominent scholars throughout history, including Marx (1853) and Wittfogel (1957), but it can best be understood through the lens of more recent resource curse theories. Irrigation can provide high crop yields, but it also allows local elites to effectively monopolize arable land in arid areas through their ownership of irrigation infrastructure. Much of the gain from irrigated agriculture therefore ends up in the hands of the elite. In that sense, irrigation potential has little effect on the polity2-index beyond its effect on instrumented land inequality. As with the Hansen overidentification test, however, this test has relatively low power since the cereal-plantation suitability is a relatively weak instrument.

water for irrigation resembles a point-source resource, a class of natural resources shown to inhibit democratization when found in abundance.

Since adoption of irrigation may be influenced by existing institutions and the degree of economic development, we use an exogenous measure of irrigation potential to estimate a causal effect of historical irrigation on autocracy. 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, cultural, 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 six points on the 21 point *polity2* scale. By implication, 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 individuals in regions with a high irrigation potential have less favorable views on democracy.

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 they should be seen as the outcome of a long historical process. Irrigation fostered a concentration of power and wealth in the hands of a small elite. The elite entrenched itself through non-democratic institutions, and both the elite and the institutions were able to survive even when the economic importance of agriculture declined.

We demonstrate this mechanism in two steps. First we show that irrigation historically was associated with a concentration of land ownership. Premodern societies were more likely to be ruled by a natural resource-controlling elite if their agriculture was based on irrigation. And countries with high irrigation potential had higher Gini-coefficients for land holdings in the middle of the 20th century. Second, we show that irrigation potential has little effect on present day democracy once historical land inequality is accounted for.

Our results contribute to the 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 deeply rooted geographical factors. The supply of water is one, as we show in this paper.

A Data Appendix

Variable	Description	Source
Absolute latitude	Distance in decimal degrees to the Equator from centroid of the country.	Thematic Mapping, www.thematicmapping.org .
Agricultural intensity	Index ranging from 1 to 4. 1 is casual agriculture and 4 is intensive agriculture.	Ethnographic Atlas, V28. Murdock (1967).
Agriculture suitability, mean	Average suitability for agriculture. We use the Ramankutty <i>et al.</i> (2002) 0.5x0.5 degree grid cell shapefile of agriculture suitability, which is constructed by (i) empirically fitting the relationship between existing croplands and both climate and soil characteristics and then (ii) combining the derived relationship with the available regional climatic and soil characteristics.	Center for Sustainability and the Global Environment (SAGE), University of Wisconsin-Maddison.
Agriculture suitability, variance	Spatial variance of the above agricultural suitability	Center for Sustainability and the Global Environment (SAGE), University of Wisconsin-Maddison.
Arable land %	Share of total area suitable for agriculture, where suitable for agriculture is defined as belonging to impact classes 1-5, shown in Figure 1.	Plate 47 of FAO GAEZ 2002 database. www.iiasa.ac.at/Research/LUC/SAEZ/ .
Area in the tropics	Share of total area located in the tropics	Nunn & Qian (2011).
Buddhists	Buddhists as a percentage of total population in year 2000	The Quality of Governance Institute, University of Gothenburg.
Catholics	Catholics as a percentage of total population in year 2000	The Quality of Governance Institute, University of Gothenburg.
Cereal / plantation	Log of $\frac{1+cerealshare}{1+plantationshare}$, where $cerealshare = \frac{land\ suitable\ for\ cereals}{land\ suitable\ for\ agriculture}$ and $plantationshare = \frac{land\ suitable\ for\ plantation\ crops}{land\ suitable\ for\ agriculture}$. Plantation crops are banana, cocoa, coffee, sugar and tea. Cereals are buckwheat, maize, millet, oat, rhye, sorghum and wheat. We define suitable as land classified as at least medium suitable by FAO.	FAO GAEZ 3.0 database.
Colony dummy	Dummy equal to 1 if the country was colonized by Europeans	Olsson (2009).
Continent dummies	Dummies for Europe, Asia, North America, South America, Africa, and Oceania.	
Demo_better	Index 1-4 measuring whether the respondent disagrees strongly (scores 1), disagrees (2), agrees (3), or strongly agrees (4) with the claim that democracy may have problems, but is the best political system. We have transformed the original variable such that higher values indicate a more favorable view on democracy.	Question e123 in the pooled World Values Survey / European Values Study.
Demo_good	Index 1-4 measuring whether the respondent thinks that a democratic system is very bad (scores 1), fairly bad (2), fairly good (3), or very good (4).	Question e117 in the pooled World Values Survey / European Values Study.
Diamond dummy	A dummy equal to one if there are diamonds in the underground.	Gilmore <i>et al.</i> (2005)

Variable	Description	Source
Duration of colony	The number of years from the country was colonized to when it became independent (only for former colonies).	Olsson (2009).
Elected headman	Societies are defined as being ruled by an elected headman if the succession of the headman was based on elections or informal consensus. For the cross country analysis, Elected headman is the share of pre-colonial societies where the local headman was elected.	Ethnographic Atlas, V72. Murdock (1967).
Elevation, mean	Mean elevation	National Centers for Environmental Information (NCEI)
Elevation, variance	Spatial variance of elevation	National Centers for Environmental Information (NCEI)
Elite	Dummy variable equal to 1 if the social stratification of the society is based on elite ownership of resources	Ethnographic Atlas, V66. Murdock (1967).
European language	Share of the population speaking a European language, %.	The Quality of Governance Institute, University of Gothenburg.
Fractionalization, ethnic	The probability that two randomly selected individuals belong to different ethnic groups	Alesina <i>et al.</i> (2003).
Fractionalization, linguistic	The probability that two randomly selected individuals belong to different language groups	Alesina <i>et al.</i> (2003).
Fractionalization, religious	The probability that two randomly selected individuals belong to different religious groups	Alesina <i>et al.</i> (2003).
Irrigation potential	Share of land suitable for agriculture where irrigation can more than double agriculture production (impact class 5). It is the dark red areas in Figure 1 as a share of the sum of the non-grey areas.	Plate 47 of FAO GAEZ 2002 database. www.iiasa.ac.at/Research/LUC/SAEZ/ .
Land Gini	The Gini coefficient the size of land holdings of all private land owners. For some countries the Gini coefficient is computed for several years. We use the Gini in the earliest year available as our measure of land inequality	Frankema (2009).
Land within 100 km of coast	Percent of total area within 100 km of ice-free coast.	Center for International Development, Harvard.
Land within 100 km of coast or river	Precent of total area within 100 km of ice-free coast or navigable river.	Center for International Development, Harvard.
Land within 100 km of all rivers	Land within 100 km of all rivers (scalerank 1-10).	Natural Earth. www.naturalearthdata.com .
Land within 100 km of large rivers	Land within 100 km of rivers with a scalerank of five or below.	Natural Earth. www.naturalearthdata.com .
Land within 100 km of navigable rivers	Land within 100 km of navigable rivers.	Portland State University. www.pdx.edu/econ/country-geography-data .
Land within tropics	Share of total area in the tropics.	Portland State University. www.pdx.edu/econ/country-geography-data .

Variable	Description	Source
Landlocked	Dummy equal to 1 if the country has no direct access to the sea.	ArcGIS software.
Legal origins	Dummy variables equal to 1 if the country's legal system originates from common law, french civil law, socialist law, and German civil law respectively. The omitted category is Scandinavian law.	The Quality of Governance Institute, University of Gothenburg.
Malaria ecology	The contribution of vectors to the force of malaria transmission.	Kiszewski <i>et al.</i> (2004)
Mineral rents	Mineral rents as a share of GDP.	World Bank
Muslims	Muslims as a percentage of total population in year 2000.	The Quality of Governance Institute, University of Gothenburg.
Oil	1000 barrels of crude oil, NGPL, and other liquids per day per capita in year 2000.	U.S. Energy Information Administration.
Part of state	Dummy equal to one if the society is part of a state. Specifically, the dummy is equal to one if the society belongs to either "large paramount chiefdoms/small states", or a "large state", zero if the society is categorized as "lacking any form of centralized political organization" or is a "petty chiefdom". Corresponds to the Centralized variable defined by Gennaioli & Rainer (2007).	Ethnographic Atlas, V33. Murdock (1967).
Polity2 index	Index measuring democracy ranging from -10 (least democratic) to +10 (most democratic).	Polity IV Project, www.systemicpeace.org/polity/polity4.htm .
Population density 1500	Population density in 500 CE.	Comin <i>et al.</i> (2010).
Precipitation, mean	Average annual precipitation over the period 1901-2000. Divided by 1000.	Mitchell <i>et al.</i> (2004).
Precipitation, yearly variance	Variance of annual precipitation 1901-2000.	Mitchell <i>et al.</i> (2004).
Protestants	Protestants as a percentage of total population in year 2000.	The Quality of Governance Institute, University of Gothenburg.
Real GDP per capita	Real GDP per capita in 2000 from Penn World Table 7.0.	Heston <i>et al.</i> (2011).
Salination	Fraction of total land area where salination reduces crop yields. Computed using FAO grid level data which divides the soil into different classes according to how much excess salts diminish the potential yields. Salination is the fraction of land which belongs to either of the classes "moderate constraints", "severe constraints" or "very severe constraints".	FAO GAEZ 3.0 database.
Settlement density	Measures, on a scale from 1 to 8, the permanency and density of settlements.	Ethnographic Atlas, V30. Murdock (1967).
Soil constraints	Measures by how much crop yields are reduced by soil constraints compared to "perfect" soil. Calculated from data on soil depth, fertility, drainage, texture, chemical and terrain slope constraints.	Plate 27 of FAO GAEZ 2002 database. www.iiasa.ac.at/Research/LUC/SAEZ/ .
State Antiquity index	Measures the number of years that a government above the tribal/chiefdom level with no substantial foreign oversight has existed within the country.	Bocksette & Putterman (2007).

Variable	Description	Source
Temperature	Average annual temperature over the period 1901-2000.	Mitchell <i>et al.</i> (2004)
Ruggedness	The Terrain Ruggedness Index, calculated by Nunn & Puga (2012).	Nunn & Puga (2012).
Total area	Total area in 1000 km, excluding inland water.	Thematic Mapping, www.thematicmapping.org.
Wheat / sugar	Log of $\frac{1+wheatshare}{1+sugarshare}$, where $wheatshare = \frac{land\ suitable\ for\ wheat}{land\ suitable\ for\ agriculture}$ and $sugarshare = \frac{land\ suitable\ for\ sugar}{land\ suitable\ for\ agriculture}$.	FAO GAEZ 3.0 database.
Years since the Neolithic Revolution	Number of years (in thousands) since the country first adopted settled agriculture.	Putterman & Trainor (2006).

B Additional empirical results

Table B1. Democracy on alternative measure of irrigation potential

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable: Polity2 index 1991-2010								
Irrigation potential class 4 and 5	-6.317*** (1.595)	-5.934** (2.789)		-6.988** (3.110)	-4.982*** (1.681)	-6.386*** (1.594)	-4.720* (2.797)	-7.246*** (2.744)
Absolute latitude		0.117* (0.067)					0.122* (0.066)	0.156* (0.086)
Precipitation		1.323 (1.197)	6.737*** (2.301)	-0.286 (3.720)			1.415 (1.167)	1.777 (1.493)
Temperature		0.019 (0.129)					0.051 (0.126)	0.048 (0.129)
Soil constraints (%)		-5.699 (4.711)					-5.078 (4.801)	-2.890 (6.130)
Squared precipitation			-2.131** (0.914)	-0.091 (1.249)				
Oil (1000 barrels/day/cap)					-5.933*** (1.834)		-5.494*** (1.629)	-3.135 (2.946)
Land within 100 km of navigable rivers %						-2.731 (2.048)	-3.374 (2.144)	0.160 (2.923)
Observations	156	156	156	156	156	156	156	156
R-squared	0.482	0.508	0.454	0.483	0.505	0.487	0.532	
Estimation	OLS	OLS	OLS	OLS	OLS	OLS	OLS	Median
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The Table mirrors Table 4 in the main text, but we here use a measure of irrigation potential based on both irrigation impact class 4 and irrigation impact class 5.

Table B2. Democracy on irrigation, controlling for more geography

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Panel A											
Dependent variable: Polity2 index 1991-2010											
Irrigation potential (%)	-5.75*** (1.51)	-5.78*** (1.56)	-5.99*** (1.69)	-5.62*** (1.54)	-5.72*** (1.52)	-6.00*** (1.56)	-5.70*** (1.99)	-5.17*** (1.94)	-5.73*** (1.57)	-5.67*** (1.51)	-8.18*** (2.46)
Terrain ruggedness, 100 m	0.03 (0.34)										
Landlocked		-0.79 (0.99)									
Malaria ecology index			-0.04 (0.08)								
Land within 100 km of coast %				1.52 (1.19)							
Land within 100 km coast/river %					0.53 (1.29)						
Land within 100 km large rivers %						-1.53 (1.28)					
Land within 100 km all rivers %							0.14 (1.73)				
Precipitation, yearly std.dev								0.00 (0.01)			
Elevation, mean									0.01 (0.01)		
Elevation, variance										0.02 (0.03)	
Growing season days % of year											-3.32 (2.29)
Estimate without irrigation	0.38	-0.80	0.07	1.97	1.16	-0.50	3.10**	0.01***	0.01	0.04	3.63**
R-squared	0.47	0.48	0.48	0.48	0.48	0.48	0.47	0.48	0.48	0.48	0.48
Observations	158	158	158	158	158	158	158	158	158	158	158
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table B2 cont. Democracy on irrigation, controlling for more geography

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel B												
Dependent variable: Polity2 index 1991-2010												
Irrigation potential (%)	-6.55*** (1.72)	-5.41*** (1.66)	-5.58*** (1.56)	-8.16*** (1.92)	-5.90*** (1.53)	-7.38*** (1.96)	-5.95*** (1.56)	-6.44*** (1.45)	-6.51*** (1.53)	-5.53*** (1.54)	-5.53*** (2.15)	-7.79*** (2.11)
Absolute latitude	0.07 (0.09)											
Absolute latitude X absolute latitude	0.00 (0.00)											
Mean agricultural suitability		0.78 (1.65)										
Variance of agricultural suitability			3.29 (3.70)									
Arable land (%)				-3.20** (1.45)								-1.93 (1.72)
Total area					0.00* (0.00)							0.00 (0.00)
Land within tropics (%)						-0.02* (0.01)						-0.00 (0.02)
(log) Wheat / sugar crops							2.59 (2.27)					
(log) Cereal / Plantation crops								2.95** (1.35)				2.17 (1.67)
Mineral rents, % of GDP									0.07 (0.13)			
Diamond dummy										1.22 (1.42)		
Salination %											-0.61 (2.91)	
Estimate without irrigation		4.28**	6.09	1.04	0.00*	0.01	1.358	1.79	0.00	1.41	-6.49***	
Observations	158	158	158	158	158	158	158	158	152	157	158	158
R-squared	0.49	0.48	0.48	0.49	0.48	0.49	0.48	0.50	0.49	0.48	0.47	0.50
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index. "Estimate of geo without irrigation" is the parameter estimate of the particular geographical variable in the same regression when irrigation potential is omitted. Column (12) of panel B includes all significant variables simultaneously. All variables are described in Data Appendix A. ***, **, and * indicate significance at the 1, 5, and 10% level. All regressions include a constant. Robust standard errors in parentheses.

Table B3. Democracy on irrigation with additional controls					
	(1)	(2)	(3)	(4)	(5)
Dependent variable: Polity2 index 1991-2010					
Irrigation potential (%)	-5.39*** (1.70)	-4.66** (1.99)	-5.01*** (1.81)	-9.02*** (2.48)	-6.69** (2.78)
Ethnic fractionalization		-4.58 (3.57)			-7.19** (3.36)
Religious fractionalization		0.34 (2.12)			-0.92 (3.63)
Linguistic fractionalization		2.81 (3.39)			5.66 (3.46)
Legal origin: Common law			1.02 (1.23)		3.47* (1.78)
Legal origin: French civil law			-0.75 (0.97)		-0.07 (1.17)
Legal origin: Socialist law			-2.99*** (0.86)		-0.99 (1.37)
Legal origin: German civil law			2.81* (1.63)		4.24 (2.73)
Years since industrialization				0.02* (0.01)	0.01 (0.01)
Observations	122	122	122	71	71
R-squared	0.47	0.48	0.53	0.55	0.63
Continents	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index. All variables are described in Data Appendix A. ***, **, and * indicate, respectively, significance at the 1, 5, and 10% level. All regressions include a constant. Robust standard errors in parentheses.

C Instrumental variable estimations

This section provides the IV counterparts of the key reduced form regressions reported in the main text. The reduced form estimates are our preferred estimates for two reasons. First, in the exactly identified setting of our analysis, the IV estimates are a rescaling of the reduced form estimates, and they do not as such provide any additional information. Second, the IV estimates are likely to be biased when we use irrigation potential as instrument for the extent of actual irrigation today.

To illustrate the bias, let x denote irrigation. Actual irrigation measured today can be written as a sum of historical irrigation using traditional methods and recently irrigated areas where irrigation is based on cheap modern technologies:

$$x_{today} = x_{traditional} + x_{modern}.$$

We observe x_{today} , but not its parts. Assume that only traditional irrigation affects democracy today and that it does so through a linear relationship:

$$democracy_i = \beta_0 + \beta_1 x_{traditional,i} + \varepsilon_i.$$

The equation above can be rewritten in terms of the observed x_{today} :

$$democracy_i = \beta_0 + \beta_1 x_{today} + \eta_i ,$$

where $\eta_i = -\beta_1 x_{modern} + \varepsilon_i$. OLS estimates of β_1 based on the equation above are biased since $cov(x_{today}, \eta_i) \neq 0$. Suppose now that we try to solve this problem by using irrigation potential as an instrument for irrigation today. We would then estimate the following first and second stage regressions:

$$x_{today} = \alpha_0 + \alpha_1 x_{potential} + u_i ;$$

$$democracy_i = \beta_0^{IV} + \beta_1^{IV} \hat{x}_{today} + v_i ,$$

where $\hat{x}_{today}$ is the predicted x_{today} from the first stage. The IV estimates are unbiased estimates of β_1 if x_{modern} and $x_{potential}$ are uncorrelated. As discussed in the main text, however, this exogeneity condition is likely to be violated since modern technologies have increased the scope for irrigation outside areas with high irrigation potential. We should consequently expect λ_1 to be negative in the following regression:

$$x_{modern,i} = \lambda_0 + \lambda_1 x_{potential,i} + v_i.$$

The estimated β_1^{IV} is consequently biased. Asymptotically, the bias takes the form:

$$\beta_1^{IV} = \beta_1 + \frac{-\beta_1 \lambda_1}{\alpha_1}.$$

We estimate $\alpha_1 > 0$ below, and our reduced form regressions in the main text suggest that $\beta_1 < 0$. We consequently have that $\beta_1^{IV} < \beta_1$, and the IV results will consequently overstate the true negative effect of irrigation on democracy. We do not face the same problem when

we estimate the reduced form regression of democracy on irrigation potential. If $\lambda_1 \neq 0$, we simply have a measurement error problem, and our estimates are consequently biased toward zero as in the OLS case (presumably less so because λ_1 is likely to be less than one). Our reduced form estimates therefore tend to underestimate the effect of irrigation, whereas the IV estimates overstate the effect of irrigation.

C.1 IV results for polity2

Columns (1)-(3) of Table C1 report the IV counterparts of the reduced form regressions in Table 4. We use data on actual irrigation from FAO. As expected, the estimated coefficients on irrigation have the same sign as the reduced form estimates. The corresponding OLS estimates are also significant (not shown), albeit numerically smaller than the IV estimates, some of which is presumably due to the bias discussed above.

We face a weak instrument problem when we include the additional geographical control variables in column (3). We are not worried by this, as part of the weakness is the consequence of adding insignificant control variables to the regression, another part is the rise in modern irrigation outside areas in Impact Class 5. The AV plot of the first stage in column (3) is shown in Figure C1.

As a robustness check, we use two additional data sets on irrigation dependence: The Freydank & Siebert (2008) estimates of land equipped for irrigation in year 1900, and data derived from the Ethnographic Atlas. In the latter case, we measure the irrigation dependence of a country as the share of societies within that country's current borders that used irrigation. The results are in both cases similar to when we use the FAO irrigation data, but the estimates are less precise due to measurement errors.

In the case of the Freydank & Siebert (2008) data, less than 15 percent of the observations in 1900 are based on actual data. The rest are estimated by extrapolating modern data backwards, by comparisons with other countries, or based on qualitative information. Moreover, the Freydank & Siebert (2008) data measures area equipped for irrigation, and provides no information on how intensively the irrigation infrastructure was used, if at all, and how high the returns were. All these shortcomings add measurement errors to the data set.

Table C1. IV estimates of democracy on irrigation									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Irrigation measure	actual2000	actual2000	actual2000	est1900	est1900	est1900	EthnoAtlas	EthnoAtlas	EthnoAtlas
Panel A. First stage									
Dependent variable: Irrigation									
Irrigation potential (%)	0.345*** (0.085)	0.244*** (0.086)	0.218* (0.127)	0.090** (0.035)	0.073* (0.041)	0.076 (0.058)	0.253*** (0.073)	0.188** (0.076)	0.193* (0.111)
Absolute latitude			-0.003 (0.003)			-0.000 (0.001)			-0.001 (0.002)
Precipitation			-0.044 (0.053)			-0.000 (0.019)			-0.006 (0.052)
Temperature			-0.001 (0.005)			-0.002 (0.002)			-0.004 (0.004)
Soil constraints (%)			0.094 (0.177)			-0.002 (0.066)			-0.008 (0.120)
R-squared	0.215	0.537	0.542	0.145	0.190	0.207	0.153	0.311	0.323
Panel B. Second stage									
Dependent variable: Polity2 index 1991-2010									
Irrigation	-32.672*** (7.194)	-28.357*** (10.222)	-26.761* (15.527)	-107.933** (43.853)	-79.487* (47.208)	-70.420 (55.649)	-38.508*** (11.921)	-30.846** (14.458)	-27.589 (18.461)
R-squared	-0.568	0.178	0.232	-1.017	-0.200	-0.004	-0.994	-0.177	-0.004
Kleibergen Paap F	16.64	7.994	2.953	6.404	3.224	1.697	11.95	6.114	3.003
A Rubin p-value	0	3.06e-05	0.0270	0	0.000126	0.0329	0	0.000126	0.0309
Observations	132	132	132	159	159	159	160	160	160
Continent dummies	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Baseline geography	No	No	Yes	No	No	Yes	No	No	Yes

Notes: IV estimates, first stage in panel A, second stage in panel B. Irrigation is instrumented with irrigation potential in a regression on the polity2 index, averaged over the period 1991-2010. The irrigation measure is actual irrigation as a share of cultivated land in year 2000 in columns (1)-(3), land equipped for irrigation in year 1900 as a share of arable land in columns (4)-(6), and the share of ethnographic societies within the borders of the country that relied on irrigation in columns (7)-(9). Geographical baseline controls are absolute latitude, temperature, precipitation, and soil quality. These are included in columns (3), (6), and (9), but only shown in the first stage estimation to show that it is their insignificance that renders the instrument weaker. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

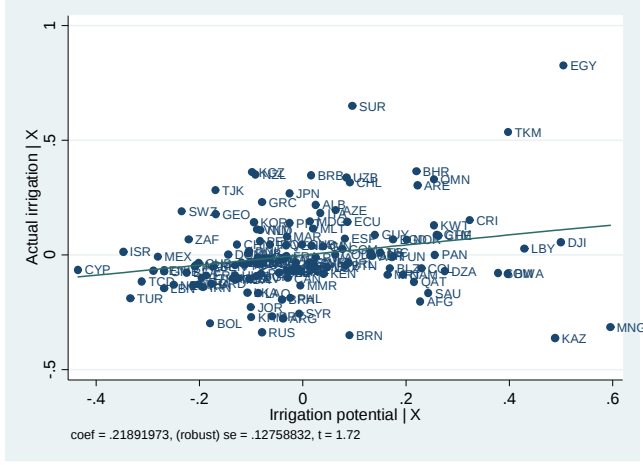


Figure C1: AV-plot Table C1, Panel A, Col 3

C.2 IV results for WVS

To calculate actual irrigation across subnational districts, we use a map of land equipped for irrigation in 2000 provided by Siebert *et al.* (2007). The level of disaggregation is $0.083 \times 0.083^\circ$, corresponding to the level of disaggregation in our irrigation potential data shown in Figure 1. In the empirical analysis of Section 4.5, we aggregate these data to the level of subnational districts of the World using a shapefile from the GADM database of Global Administrative Areas.

In Table C2 we report the IV estimates of the effect of irrigation on attitudes towards democracy across subnational world districts. The IV estimates correspond to the reduced form estimates in Table 8 in the main text.

Table C2. IV estimates of democracy on actual irrigation 2000

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. IV estimates: First stage						
Dependent variable: Area equipped for irrigation 2000, % of arable land						
Irrigation potential (%)	0.376*** (0.054)	0.321*** (0.058)	0.363*** (0.063)	0.394*** (0.060)	0.329*** (0.065)	0.375*** (0.071)
Muslim			0.016* (0.009)			0.012* (0.007)
R-squared	0.680	0.701	0.699	0.688	0.680	0.669
Panel B. IV estimates: Second stage						
Dependent variable	demo_good	demo_good	demo_good	demo_better	demo_better	demo_better
Area equipped for irrigation 2000, % of arable land	-0.157** (0.078)	-0.184* (0.101)	-0.157 (0.098)	-0.189** (0.084)	-0.262** (0.118)	-0.264** (0.114)
Muslim			0.048*** (0.017)			0.024 (0.048)
Kleibergen-Paap F	47.84	30.66	33.16	43.39	25.19	27.56
Anderson Rubin p	0.0336	0.0474	0.0881	0.0213	0.0155	0.0114
Observations	96,315	95,444	74,854	62,342	61,675	47,927
Country FE	Y	Y	Y	Y	Y	Y
Individual controls	Y	Y	Y	Y	Y	Y
Geo controls	N	Y	Y	N	Y	Y

Notes. IV estimates of attitudes towards democracy on actual irrigation, instrumented with irrigation potential, first stage shown in panel A, second stage in panel B. The unit of analysis is individuals. All regressions include country and year fixed effects, age, gender, a dummy for agricultural worker, and 10 income and 8 education fixed effects. Geo controls refer to district level controls for absolute latitude, precipitation, temperature, and soil constraints. All variables described in Data Appendix A. Standard errors, clustered at the district level, are reported in parentheses. Asterisks ***, **, and * indicate significance at the 1, 5, and 10% level.

C.3 IV across ethnographic societies

Table C3 shows the IV estimates corresponding to Table 10 in the main text. See Section 3.2 for a description of the irrigation data.

Table C3. IV estimates of elite stratification on actual historic irrigation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. First stage								
Dependent variable: Irrigation dummy								
Irrigation potential (%)	0.431*** (0.106)	0.354*** (0.114)	0.453*** (0.106)	0.374*** (0.098)	0.437*** (0.108)	0.433*** (0.105)	0.335*** (0.106)	0.381*** (0.083)
Settlement complexity			0.014 (0.010)				-0.004 (0.010)	0.004 (0.008)
Agricultural intensity				0.161*** (0.018)			0.151*** (0.019)	0.154*** (0.016)
Part of state					0.119*** (0.039)		0.043 (0.037)	0.039 (0.032)
Local headman election						0.071 (0.045)	0.026 (0.040)	
R-squared	0.359	0.383	0.362	0.481	0.375	0.364	0.490	0.466
Panel B. Second stage								
Dependent variable: Elite stratification								
Irrigation dummy	0.838*** (0.273)	0.917*** (0.355)	0.787*** (0.260)	0.950*** (0.327)	0.830*** (0.273)	0.835*** (0.270)	0.951** (0.381)	0.822*** (0.251)
Settlement complexity			-0.014 (0.009)				-0.002 (0.011)	-0.012 (0.008)
Agricultural intensity				-0.137** (0.053)			-0.124** (0.059)	-0.123*** (0.041)
Part of state					0.073 (0.050)		0.018 (0.043)	0.013 (0.034)
Local headman election						-0.058 (0.042)	-0.029 (0.040)	
Kleibergen Paap F	16.48	9.590	18.28	14.65	16.39	16.94	10.03	20.93
Observations	569	569	569	569	569	569	569	750
55 language dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Century fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic controls	No	Yes	No	No	No	No	Yes	Yes

Notes: IV estimates of elite stratification on actual historical irrigation, instrumented with irrigation potential. The first stage results are shown in panel A and the second stage results in panel B. Actual historic irrigation is measured by a dummy equal to one if the society had intensive irrigation, zero otherwise. The dependent variable in panel B, elite, is a dummy variable equal to one if the society is ruled by an elite which bases its power on control of a natural resource. All control variables are described in Table 10. ***, **, 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.

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