Growing Collectivism: Irrigation, Group Conformity and Technological Divergence

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Abstract

This paper examines the agricultural origins of collectivist cultures that emphasize group conformity over individual autonomy. In line with the hypothesis that collaboration within groups in pre-industrial agriculture favored the emergence of collectivism, I document that societies whose ancestors practiced irrigation agriculture are more collectivist today. The positive effect of irrigation on contemporary collectivist norms holds across countries, sub-national districts within countries, and migrants. For causal identification, I instrument the historical adoption of irrigation by its geographic suitability. Furthermore, this paper establishes that, by favoring conformity, irrigation agriculture has contributed to the global divergence of technology. I find that the historical use of irrigation is associated with lower contemporary innovativeness of countries, cities, and migrants, and a stronger selection into routine-intensive occupations, and that the initial technological advantage of irrigation societies was reversed after 1500.

Keywords: Agriculture; Culture; Collectivism; Persistence; Innovation; Job Tasks

JEL Classification: N00, N50, O10, O30, Z10

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"Cooperation, such as we find it [...] say in the agriculture of Indian communities is based [...] on the fact, that in those cases, each individual has no more torn himself off from the navel-string of his tribe or community, than each bee has freed itself from connexion with the hive."
— Karl Marx, *Das Kapital (1867)*

1 Introduction

Why did Europe experience rapid technological progress after the mid-16th century but not the Middle East or Asia, which were more advanced at the time?[1] A prominent answer to this central question in long-run development links the divergence in science and technology to profound cultural differences between the "East" and the "West" (Weber, 1958; Rosenberg and Birdzell, 1986; Landes, 1999). "Eastern cultures" are commonly described as collectivist: they place the group above the individual, value conformity and obedience to group norms, and expect loyalty from group members. "Western cultures" are instead individualist: they emphasize individual autonomy and differences between individuals. An individualist outlook presumably encouraged individuals to create novel and unique technologies, whereas the focus on conformity likely impeded the pursuit of unconventional ideas that challenge existing concepts (Markus and Kitayama, 1991; Mokyr, 1992). Yet, while individualism-collectivism is regarded as a key cultural dimension and an important driver of economic growth, empirical research into its origins and impact on patterns of technological change is limited.[2,3]

This paper examines the role of pre-industrial agricultural techniques in explaining the long-run divergence of culture and innovative activities. It tests the hypothesis that the need to collaborate within groups in traditional irrigation agriculture favored the emergence of collectivist cultures (e.g. Barry III *et al.*, 1957; Mann, 1986; Wyer *et al.*, 2013). In line with this argument, I document that descendants from societies that practiced irrigation agriculture in pre-industrial times have stronger collectivist values today. While the focus on conformity rather than individual autonomy facilitated coordination of production in irrigation agriculture, it plausibly hampered innovative activities, and inhibited the creation of the many small-scale innovations that propelled the takeoff to industrial production (Mokyr, 2016). My findings support this view: irrigation societies were technologically more advanced prior to 1500, but systematically fell behind afterwards. Today, descendants of societies that practiced irrigation are less innovative, regard independence as unimportant in their job, and select into routine-intensive occupations.

The use of irrigation allowed pre-industrial populations to grow a wide range of crops, such as tubers and cereals, irrespective of rainfall levels. Its construction, maintenance and management, however, required extensive collective efforts and attached farmers to communities that

[1] This question was famously articulated by Needham (1954-): "[T]he essential problem [is] why modern science had not developed in Chinese civilization (or Indian) but only in Europe. [...] What were the inhibiting factors [...] which prevented the rise of modern science in Asia?" China, in particular, was the world's technological leader and as a centralized state had all the pre-requisites commonly associated with economic success, such as a state and a bureaucracy (Mokyr, 1992).

[2] The contemporary association between collectivist cultures, technology, and income has been documented by Gorodnichenko and Roland (2011a, 2016).

[3] A more precise understanding of the evolution and persistence of norms that affect technological change is particularly important in the light of efforts by governments to promote innovation. For example, the recent rapid economic growth of several Asian countries, including China, has been based on technological adoption and imitation, coupled with large investments (Liang, 2010). To sustain high growth in the future, a transition from investment to innovation-led growth is crucial (Zilibotti, forthcoming). Entrepreneurs, such as Kai-Fu Lee, have identified a culture of conformity and obedience as a main hindrance to this transition: "Before China gets to that level of innovation, it has to overcome a lot of issues that are cultural and about education, where there is emphasis on discipline and obedience." (BBC, 2012, http://www.bbc.com/news/world-asia-20041320).

governed the optimal coordination of the water supply with strict rules and obligations (e.g. Mann, 1986; Aoki, 2001; Nisbett, 2010). Since individual deviations from collective decisions could have severe consequences for the welfare of irrigation communities - e.g. by increasing the likelihood of pests or water shortages - conformity and subordination of the individual to the group were the optimal behavioral norms for the functioning of the irrigation network. By punishing excessive autonomous behavior and free-riding, irrigation communities achieved to sustain intra-communal cooperation and conformity even in the absence of formal enforcement institutions (Ostrom, 1990; Ostrom and Gardner, 1993). If those cultural norms that maximize survival probabilities are selected through an evolutionary process (Boyd and Richerson, 1988, 2004), then irrigation agriculture could have favored the evolution and persistence of collectivist - rather than individualist - cultures.[4] However, even though collectivism was optimal for coordination in agricultural times, its benefits could have been lost in later stages of development. Since conformism likely decreased societies' capacity to innovate, the collectivist cultures of irrigation societies could have contributed to their relative stagnation vice versa more individualist societies in the industrial era.

Building on these insights, I examine the effect of past agricultural production on culture and innovation, using information on the importance of irrigation for the ancestors of contemporary populations that I construct from ethnographic data. My baseline empirical analysis controls for a number of important geographic covariates of irrigated agriculture, including rainfall levels, overall agricultural productivity, and societies' historic economic and institutional development. Nonetheless, the adoption of irrigation could be driven by other unobserved confounding factors that, together with measurement error, would bias the estimates. To address endogeneity, I propose an instrumental variable strategy that uses the geographic suitability for irrigated agriculture as instrument for the actual adoption of irrigation. Reassuringly, irrigation suitability predicts positively the adoption of irrigation by ethnic groups in the past. The validity of the IV estimation requires that irrigation suitability influences outcomes only through the actual adoption of irrigation in the past, controlling for geographical and historical characteristics. I directly examine the main concern that irrigation suitability is correlated with other geographical features that could affect norms and technology.

The first part of the empirical analysis tests the effect of historic irrigated agriculture on contemporary culture. Results from OLS and 2SLS regressions lend support to the hypothesis that ancestral irrigation helped to produce a culture of collectivism. These findings appear i) across countries, conditional on a wide range of country controls and continental fixed effects that account for differences across world regions and ii) across up to more than 190,000 individuals living in over 900 sub-national districts, conditional on individual controls and either continental or country fixed effects that control for country-wide institutional differences. The magnitudes of the effects are economically meaningful. Consider a country where all citizens descend from ancestors that have used irrigation in the past such as South Korea. If Koreans had not used irrigation traditionally, its average collectivism score (measured between 0-100) would drop by between 22% (OLS) to 43% (IV), from a high value of 82 (83 percentile) to a much lower level

[4]Already Marx, in his description of the "Asiatic Mode of Production", stressed how irrigation agriculture affected the structure of a society, tying the individual to the community and restricting his autonomy (Lubasz, 1984; Marx, 1939 [1858]). Marx noted that the irrigation communities of Asia operated under "the presupposition that the individual does not become independent *vis-a-vis* the community", thereby stifling individualism and social change (Marx, 1939 [1858]).

similar to Uruguay (43 percentile) or Israel (28 percentile).

I then investigate heterogeneous effects of irrigation, and test for the inter-generational transmission of collectivist norms. I find that irrigation systems that required centralized coordination, commonly along large rivers or in arid climates, are associated with stronger preferences for obedience, in line with the "hydraulic empire" hypothesis of Wittfogel (1957). Irrigation systems in mountainous areas, traditionally managed by farmers themselves, are associated with increased norms of cooperation (in line with Weissing and Ostrom, 1991; Bardhan, 2000). This implies that some historic irrigation systems gave rise to a more hierarchical, authoritarian culture that could have facilitated the development and persistence of autocratic institutions - as documented by Bentzen *et al.* (2016).[5] To further test for a cultural channel linking irrigation and political institutions, I differentiate the effect of irrigation suitability computed in the ancestral homelands of populations from the local suitability of the lands where populations currently reside. I find that the ancestry-based measure of irrigation suitability positively predicts autocratic institutions, even more strongly than local suitability, and is associated with a reduced likelihood for political protest. This suggests that the emergence of collectivism is an additional mechanism behind the persistent influence of past irrigation on institutional quality.[6]

Furthermore, I find evidence for inter-generational transmission as a mechanism of persistence: past irrigation predicts collectivist cultural traits in a sample of 1st and 2nd generation European migrants, controlling for individual characteristics and comparing migrants that reside within the same country, or even within the same sub-national region.[7] Assessing factors that affect the transmission of collectivism reveals that greater ethnic fractionalization in the host country strengthens persistence, while larger public spending on old age security decreases material interdependencies and weakens the persistence of collectivist norms.

The second part of this paper explores how historic irrigated agriculture shaped technology. Consistent with the idea that collectivist norms impede technological creativity, I document that populations of countries whose ancestors used irrigation in the past produce today significantly less scientific articles per capita.[8] The magnitude of the effect is large and implies that South Koreans, for example, would today produce up to two times more articles per capita, a level similar to Canada, if their ancestors had not traditionally used irrigation. The effects on Chinese research productivity would be even larger, up to an increase by 250%. To study the effect of past irrigation on innovation within countries, I build a novel dataset that measures research productivity in 1,893 cities. I document a similar negative effect of past irrigation on contemporary innovation conditional on country fixed effects. Moreover, in line with historical accounts, the analysis of past technological progress reveals that irrigation societies were technological leaders prior to 1500, but fell back after the mid-16th century. This technological reversal is estimated over the long-run from 1000 BC to today, and appears in both cross-sectional regressions and in panel estimations that take into account time-invariant country effects.

[5] Different from Bentzen *et al.* (2016), I measure the actual adoption of irrigation using ethnographic data. In addition, I compute irrigation suitability as the population-weighted average of suitability measured in the geographic areas home to the ancestors of contemporary societies - rather than average irrigation suitability of the environment in which societies reside today. This allows me to separate the culturally-embodied effect of past irrigation from the effect of local irrigation suitability.

[6] This is consistent with the idea that collectivism and autocratic institutions are complements, as argued by (Gorodnichenko and Roland, 2015).

[7] This analysis follows the epidemiological approach of Fernández (2008); Fernandez and Fogli (2009).

[8] A large literature outside of economics documents the negative effects of collectivist norms on creativity and idea creation (e.g. Nemeth and Staw, 1989; Leung and Wang, 2015; Dollinger *et al.*, 2007; Kasof *et al.*, 2007).

While the reduced-form results between technology and irrigation are consistent with alternative interpretations, two tests allow me to gather evidence evidence for a cultural mechanism. First, ancestral irrigation suitability, i.e., suitability computed in the ancestral homelands of contemporary populations, predicts innovation much stronger than local irrigation suitability. Second, I can test directly for a cultural mechanism using innovativeness of US immigrants that live outside their country of origin. I find that migrants from irrigation societies are less likely to patent, to publish books or scientific articles, and to mention independence as an important job characteristic, even when they face the same external environment in the United States. This specification allows to rule out that home country characteristics that are correlated with the traditional use of irrigation, such as institutional quality, are behind its association with innovation. To corroborate the effects on technological change, I document, at the country-level and among migrants, that descendants of irrigation societies are more likely to select into jobs that are intensive in routine tasks and require rule-following rather than independent behavior.

Taken together, my findings suggest that at least parts of the effect of past irrigation on innovation works through its effect on cultural norms. Irrigation shaped a culture of collectivism that facilitated the efficient coordination of production in agricultural economies, giving irrigation economies a technological lead in pre-industrial times. However, the focus on group conformity instead of independence hampered innovativeness and became a disadvantage in the modern growth regime. The cultural consequences that evolved from the adoption of irrigation agriculture paved the way for a reversal of technology in the long-run.

Related Literature. This paper relates to several literatures. Foremost, it contributes to the study of the historical origins of culture and economic development.[9] A growing literature in economics documents that geography and its effects on subsistence agriculture in pre-industrial times favored the emergence of various cultural beliefs, from gender equality (Alesina *et al.*, 2013), to preferences for hard work (Fouka and Schlaepfer, 2017), time preference (Galor and Özak, 2016), and trust (Buggle and Durante, 2017).[10] Litina (2016) shows that more productive land that decreased the need for cooperation in pre-modern times is associated with lower levels of trust and development today. Olsson and Paik (2016a,b) document a long-run reversal of development, showing that areas within Europe that transitioned later to agriculture are today wealthier and more individualistic. My findings contribute to this literature by providing the first comprehensive evidence that the need of pre-industrial irrigation farmers to cooperate within groups shaped collectivist norms. Furthermore, I show that, by affecting culture, past agriculture led to a global technological reversal. Different from existing contributions (e.g. Litina, 2016; Buggle and Durante, 2017), my paper focuses on the effects of collaboration within narrow groups of people in the management of irrigation on the degree of subordination to groups, and the strength of conformity to group norms. Importantly, the influence of ancestral irrigation is robust to controlling for agricultural suitability (Litina, 2016), historical dependence on agriculture, and the timing of the Neolithic Revolution (Olsson and Paik, 2016a).

My paper also intersects with cross-cultural research that investigates empirically the origins of collectivism (e.g. Fincher *et al.*, 2008; Welzel, 2013; Talhelm *et al.*, 2014). My results complement and generalize the findings in Talhelm *et al.* (2014), who document that students from

[9] For overviews of these empirical literatures see Nunn (2012) and Spolaore and Wacziarg (2013).

[10] Theoretical and empirical contributions on the persistence of cultural traits include Bisin and Verdier (2001); Dohmen *et al.* (2012); Voigtländer and Voth (2012).

rice-growing areas in China think more collectively compared to students from wheat growing areas. In estimations reported in the Appendix, I suggest a way to disentangle the effects of rain-fed from irrigated rice cultivation, and find results indicating that the relationship between rice agriculture and collectivism is driven by rice grown under irrigation.

This study also provides new evidence on the deep determinants of innovation and labor-market sorting. My findings relate to papers on the impact of collectivism on innovativeness across countries (Gorodnichenko and Roland, 2011a, 2016), and to studies that analyze the cultural background of innovators (e.g. Hunt and Gauthier-Loiselle, 2010). The migrant analysis documents that innovation at the individual level is affected by a person's culture. In addition, my findings add to the literature in labor economics on job tasks (e.g. Autor *et al.*, 2003; Acemoglu and Autor, 2011). They suggest that culture is an important determinant of labor-market sorting, which so far has only been studied sparsely (see e.g. Krueger and Schkade, 2008). A notable exception is Campante and Chor (2017), who establish empirically and theoretically a two-way relationship between attitudes towards workplace obedience and specialization in routine tasks that mirrors some of my findings. Relative to these literatures, my study finds that innovativeness and labor-market sorting into jobs have "deep-roots": they are influenced by a person's cultural heritage, parts of which emerged from traditional agricultural practices.

My study also adds to previous theoretical and empirical work on cooperation in the management of common pool resources, in particular irrigation networks (e.g. Ostrom, 1990; Weissing and Ostrom, 1991; Bardhan, 2000). Regarding the socio-economic effects of irrigation, Bentzen *et al.* (2016) document a strong positive association between irrigation suitability and autocratic institutions across countries.

Finally, my study relates to a literature that examines variation in family and kinship ties, a concept that is connected to individualism and collectivism (Banfield, 1958; Alesina *et al.*, 2015; Alesina and Giuliano, 2013). Mann (1986) argues that nuclear families emerged in rain-fed agricultures, while irrigation agriculture favored extended families. Enke (2017) documents that strong historical kinship ties predict in-group orientation of societies today. Several studies have linked Europe's weak kinship ties to its economic success, in particular relative to the clan-based societies of Asia (Greif, 2006; Greif and Tabellini, 2010, 2017; Schulz, 2016). de la Croix *et al.* (forthcoming) argue that one reason for Europe's technological advantage after the medieval period was an easier diffusion of knowledge among independent individuals compared to clan-based societies. I provide a complementary mechanism for the global divergence of technology, and show that parts of the technological differences stem from reduced innovation in societies that developed weaker preferences for independence.

The next section defines collectivism and outlines the conceptual framework and hypotheses. Section 3 describes the empirical strategy and the data construction. Section 4 reports results of ancestral irrigation on cultural norms of collectivism. Section 5 discusses the empirical findings of ancestral irrigation on innovation and patterns of occupational specialization. Section 6 concludes.

2 Conceptual Framework & Hypotheses

2.1 Defining Collectivism

The individualism-collectivism cleavage is regarded as a key cultural dimension to describe societies and has been the subject of considerable research in cross-cultural studies (Oyserman *et al.*, 2002).[11] The term collectivism, often loosely defined, generally describes a set of cultural values that reflect the subordination of the individual to the group, and the former's dependency on the group for survival and social security. Hofstede (1980, p.45), for example, defines collectivism as a "tight social framework in which people distinguish between in-groups and out-groups; they expect their in-group (relatives, clan, organizations) to look after them, and in exchange for that they feel they owe absolute loyalty to it." Hofstede's definition implies that collectivism is a culture of *interdependence*, in which the individual's conformity to the group is crucial, but also comes at the cost of reduced personal autonomy (Wyer *et al.*, 2013). In contrast, "individualism implies a loosely knit social framework in which people are supposed to take care of themselves and of their immediate families only." Hofstede (1980, p.45). Thus, individualism is the diametric opposite of collectivism, and describes a culture of *independence*. Moreover, collectivism can further be divided into a horizontal form, where groups emphasize equality and cooperation among similar individuals, and a vertical form, where hierarchies are pronounced and people defer to authority (Singelis *et al.*, 1995). In a similar vein, Schwartz (1994) refers to individualism-collectivism as autonomy versus embededdness, where the former pronounces independence and the latter conformity.

Figure 1 illustrates the individualism/collectivism cleavage across countries using data from Hofstede *et al.* (2010). The variable measures to which extent people in a society are integrated into groups. The most collectivist countries are Vietnam, South Korea, Pakistan, Ecuador, and Guatemala, whereas the United States, followed by Australia and Great Britain, are among the most individualist countries in the world.

The self-perception of being socially independent or interdependent has consequences for interpersonal relationships, individual cognitive styles and, more broadly, a number of important socio-economic outcomes on the aggregate level (Markus and Kitayama, 1991; Nisbett and Masuda, 2003). For example, in collectivist societies cooperation, such as in the provision of welfare, is limited to in-group members (van Hoorn, 2014). Collectivist cultures also demand a constant adjustment of behavior for better coordination of the group and are not favorable towards individuals who stand out. Obedient behavior and an aversion towards the disruption of group harmony can hamper individual incentives to innovate and engage in collective political action (Gorodnichenko and Roland, 2011a, 2015).

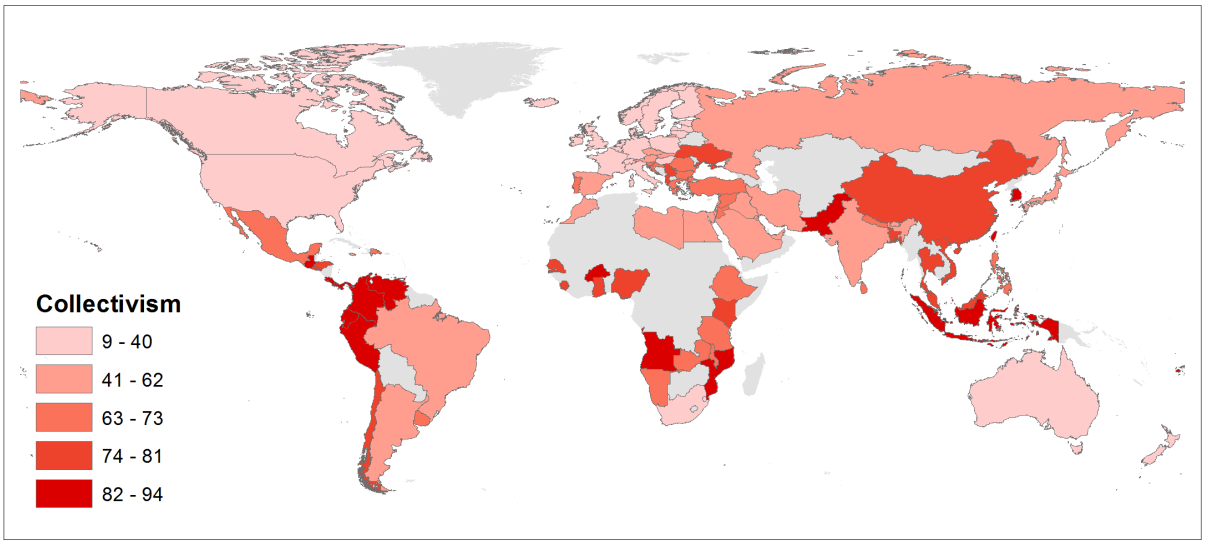
2.2 The Agricultural Origins of Collectivist Norms

A prominent hypothesis in cultural psychology argues that ecological conditions that made individuals depend on the group for subsistence production supported the emergence of collectivist cultures (e.g. Wyer *et al.*, 2013).[12] Cultural traits of individualism are instead more likely

[11] Scholarly interest in analyzing the extent to which individuals are independent from or embedded in various groups goes back at least to the classical works of Emile Durkheim, Max Weber, and Ferdinand Tönnies.

[12] More generally, cultural norms can be defined as "rules of thumb" that guide behavior in uncertain situations. Boyd and Richerson (1988, 2004) model the emergence of culture as an evolutionary process that selects those behavioral norms that maximize the chances of survival in a given environment. Over time, these behavioral

Figure 1: Collectivism across Countries



Note: This figure shows the average degree of collectivism across countries, based on Hofstede *et al.* (2010).

to have emerged in ecological environments where self-reliance and individual independence in agriculture guaranteed subsistence (e.g. Barry III *et al.*, 1957). In particular, the use of irrigation for watering crops has been highlighted for demanding a great degree of group effort - "far in excess of the agricultural norm" (p. 46 Mann, 1986) - making farmers (hydrologically) interdependent (e.g. Mann, 1986; Aoki, 2001). Irrigation agriculture has a long history, and some of the first irrigation systems in Mesopotamia reach back more than 5,000 years (Vasey, 2002). Irrigation allows farmers to grow crops in environments of limited rainfall by using artificial sources of water, like surface water from rivers and lakes, or groundwater. This water is channeled from its source and distributed to the fields via a system of canals and dams.

Yet, while irrigated agriculture allows crops to grow in the absence of rain, it requires a high level of coordination and cooperation. In addition to the collective construction and maintenance of irrigation systems, farmers need to solve many difficult coordination issues (Janssen, 2007). In particular, they must jointly decide on the optimal timing of harvests, as well as cycles of wet and dry phases, in order to avoid water shortages and outbreaks of pests that can severely affect crop yields.[13] It is therefore crucial for irrigation communities to both coordinate an optimal planting schedule and meticulously adhere to it. While community welfare is maximized if all farmers respects collective decisions (e.g. the planting schedule), each individual farmer has incentives to deviate, e.g., take water in higher amounts or at unauthorized times in order to increase private yields (e.g. Ostrom and Gardner, 1993). Of course, free-riding and other deviant behavior jeopardize the group's total harvest and welfare, for example by increasing the risk of pest outbreaks and water shortages. Therefore, in irrigation agriculture group cooperation, conformity and subordination of individual interests to the group, rather than autonomy, are behavioral norms that maximize survival probabilities, and these norms could have - over time - become part of the culture of irrigation societies (following Boyd and Richerson, 1988, 2004).

Whether sustained cooperation in irrigation required a centralized authority, or whether co-

norms become more widespread and establish themselves as culture.

[13] For example, a typical coordination problem concerns the optimal control of pests across connected fields (Janssen, 2007). Pests are most efficiently kept under control if all farmers harvest simultaneously. However, a joint harvest implies a common planting date, in turn increasing the risk of water shortages. To balance the risk of pests and water shortages, coordination on an exact planning of the planting and harvest date is necessary.

ordination was achieved via community cooperation, is the subject of considerable debate in anthropology (Janssen, 2007; Hunt, 1988). Most prominently, Wittfogel (1957) argued that irrigation favored political centralization, strict social hierarchies, and authoritarian political institutions.[14] Centralized coordination in large hydraulic states aside, decentralized coordination among community members has also historically been - and still is - an equally important way of managing irrigation networks (Ostrom, 1990; Ostrom and Gardner, 1993; Molle, 2004). Research on community irrigation in Asia, for instance, documents that farmer-managed irrigation systems are widespread, and have existed for centuries (Molle, 2004). Similarly, Mann (1986) noted that "the vast majority of Chinese irrigation schemes - and indeed those of every country yet investigated - were relatively small, confined to a village or a group of villages. They were usually organized by locals, sometimes villagers and more often local lords." (Mann, 1986, p. 94).[15] Generally, even without third party enforcement, irrigation communities were able to sustain cooperation and conformity. To deter potential defectors, they commonly used social punishment such as ostracism, or threatened to cut the defector off from the irrigation network (Wijermans and Schlüter, 2014). The Japanese expression *mura hachibu* ("80 percent exclusion from the village") illustrates how the practice of excluding a free-riding rice farmer from all communal life became embodied even in language (Aoki, 2001).

While farmer-managed irrigation can be large in scale, community irrigation systems are, on average, much smaller in size (Molle, 2004). Consistent with the details of Wittfogel's hypothesis, centralized authority has emerged particularly in areas characterized by a) arid climates and b) a large water source (e.g. the Nile, Hindus Valley) (Wittfogel, 1957; Hunt *et al.*, 1976). That is, coordination by a centralized authority is more beneficial if management issues are more complex, e.g., if the size of the community involved is large or if there is a high degree of water stress. For instance, large-scale valley irrigation networks in ancient China were centrally managed (Mann, 1986). On the other hand, the smaller, farmer-managed, irrigation systems were more common in environments with smaller and more dispersed rivers, particularly in rugged lands and areas of high altitude (Molle, 2004).

To sum, the ethnographic evidence suggests that irrigation agriculture favored the emergence of group identification, norms of group conformity, and obedience (i.e., collectivism), and discouraged individual autonomy. In addition, centralized coordination of large-scale irrigation might have resulted in an even stronger acceptance of hierarchy and authority, while vertical community cooperation in small scale irrigation networks may have favored more cooperative norms. The persistence of collectivism in the long-run might be attributed to inter-generational transmission from parents to children.[16] Yet, it is plausible that collectivist norms interacted

[14]Many anthropologists argue that often the despotic state preceded the construction of irrigation facilities rather than following from them (Adams, 1960; Lanning, 1967). However, evidence in support of Wittfogel's hypothesis is provided by Bentzen *et al.* (2016), who document a positive association between irrigation suitability and the degree of contemporary autocracy across countries.

[15]Perhaps the most sophisticated and well-studied stateless irrigation system is the *Subak* system in Bali (Lansing, 2009). Dating back more than a thousand years, it is composed of about 1,300 farming communities (*Subaks*). Each community manages the water supply to a block of rice fields using a complex planting schedule and a network of water temples for coordination across *Subaks*.

[16]The inter-generational transmission of collectivist values is well described in cultural-psychology research. According to Nisbett and Masuda (2003), children learn independence or interdependence at very young ages. For example, Western babies sleep in beds that are separated from their parents, while Asian babies always sleep with at least the mother. In addition, while American mothers teach their children to focus on objects, Japanese mothers direct their children's focus towards feelings and the relationships between objects.

with formal institutions that facilitated the persistence of cultural differences over time.[17]

2.3 Irrigation, Collectivism, and Technological Divergence

Collectivist norms and thinking have been argued to be a hindrance for innovation and technological progress - the prime drivers of economic growth (Triandis *et al.*, 1988; Nemeth and Staw, 1989; Leung and Wang, 2015). Group identification and conformity, rather than independence, discourages collectivist individuals to differentiate themselves from the group, and lowers their willingness to distort group cohesion with radical or unconventional concepts. Ultimately, this prevents technological creativity. For example, Tatsuno (1990) describes how the Japanese culture of conformity suppresses the expression of ideas, as people "who generate deviant, wild or weird ideas will be punished by social sanctions". Empirical evidence across students (Dollinger *et al.*, 2007; Kasof *et al.*, 2007), and nations (Gorodnichenko and Roland, 2016) support the negative influence of collectivism on creativity and the rate of innovation. If irrigation agriculture fostered collectivism, it is likely that societies that used irrigation are less innovative today.[18]

A negative effect on innovation would, however, contrast with the observation that irrigation societies were technologically more advanced in pre-industrial times. This suggests the following hypothesis:[19] In agricultural economies in which technology evolves slowly, group conformity allowed a better coordination of production and a more efficient adoption of existing technologies. This leads to a head start of irrigation societies. The transition from agriculture to industry and sustained growth, however, required a rapidly expanding stock of knowledge created by many small-scale entrepreneurs (Mokyr, 2016). In this stage of development, norms of conformity lose their benefits and contribute to a reversal of technological progress over time.[20]

2.4 Motivating Evidence

To further motivate the empirical investigation, Figure 2 provides a comparison of the characteristics of historical societies that used irrigation to those that did not. Irrigation societies differed in several dimensions: Most importantly, they score higher on a measure of collectivism, computed as the difference between the degree of inculcation of obedience rather than self-reliance in children. In addition, adults in irrigation societies were less mobile and more strongly tied to the community. Regarding institutional characteristics, irrigation societies were more likely to use formal sanctions and enforcement mechanisms to impose community decisions, but the selection of local leaders was nor more or less democratic. Moreover, political institutions of

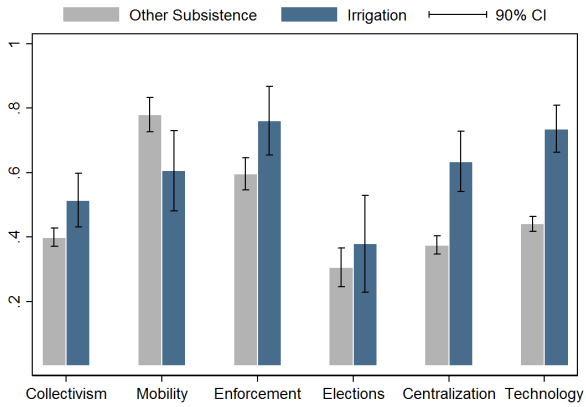
[17] See Gorodnichenko and Roland (2015) for the contemporary effect of collectivism on autocratic institutions.

[18] While I focus empirically on knowledge creation, a second important channel is the diffusion of knowledge. Relative to group based societies, in which knowledge is transmitted only across group members, interactions between independent individuals allow for a wider diffusion of knowledge (see e.g. de la Croix *et al.*, forthcoming).

[19] The hypothesis is consistent with the model predictions of Gorodnichenko and Roland (2016), who argue that collectivist societies have an advantage for coordination that results in a higher (initial) level of development. On the other hand, individualist societies create more innovations which increases the growth rate of the economy, allowing them to ultimately take over. A related argument has been made by Ashraf and Galor (2011). Ashraf and Galor (2011) document a trade off between cultural assimilation and diffusion, where the former increased efficiency in agricultural economies, but the latter eased technological adoption when technological change was rapid.

[20] Already Hume ([1742] 2001) linked social conformity to the stagnation of Chinese scientific progress: "None had courage to resist the torrent of popular opinion. And posterity was not bold enough to dispute what had been universally received by their ancestors. This seems to be one natural reason why the sciences have made so slow a progress in that mighty empire."

FIGURE 2: CHARACTERISTICS OF PRE-INDUSTRIAL SOCIETIES



NOTE: Ethnic groups from the Standard Cross Cultural Sample. See Data Appendix for a variable description.

irrigation societies were more centralized, and they used more advanced technologies historically. Overall, the evidence presented in Figure 2 confirms the ethnographic description of traditional irrigation societies.

3 Data and Empirical Strategy

3.1 Baseline Analysis

To identify the long-term impact of traditional irrigation, the baseline analysis estimates OLS regressions of of the following form:

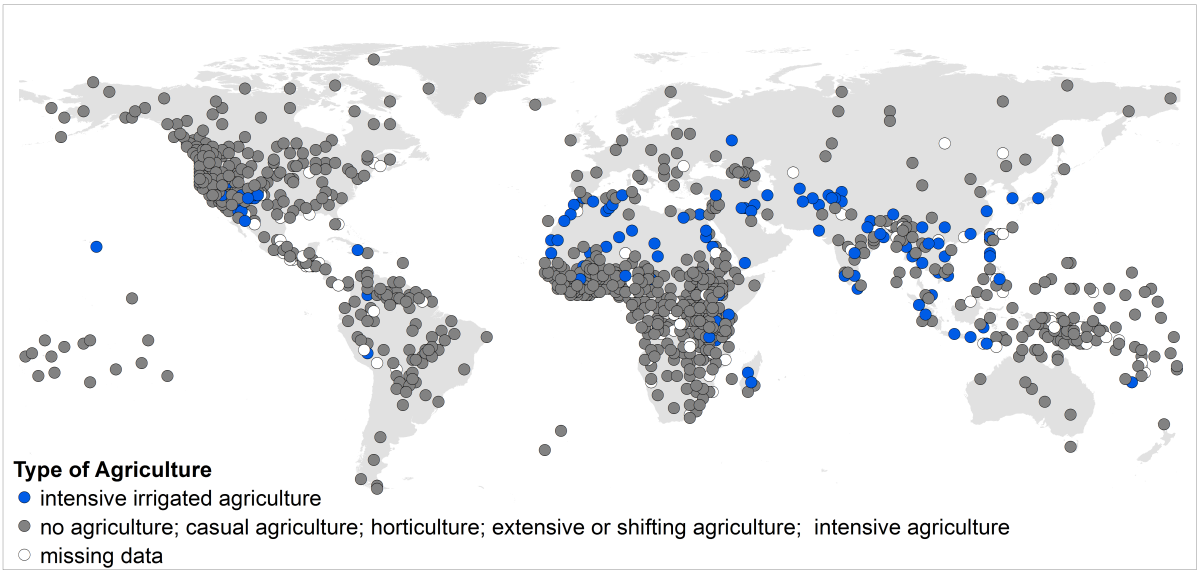
$$y = \alpha + \beta Ancestral\ Irrigation + \delta X + \varepsilon \tag{1}$$

where y is an outcome (cultural norms or technology) and *Ancestral Irrigation* measures the importance of irrigation for ancestors of current populations. X is a vector of baseline control variables that includes geographic and ethnographic covariates. The following paragraphs describe the construction of the irrigation variable and the baseline controls.

Ancestral Irrigation. To measure whether the ancestors of today's societies used irrigation, I use ethnographic data on the type of traditional agriculture practiced by the 1,267 ethnic groups of Murdock's *Ethnographic Atlas*.[21] Variable v28 of the *Ethnographic Atlas* provides information on the intensity of agriculture, ranging from (1) *no agriculture*, (2) *casual agriculture*, (3) *extensive or shifting agriculture*, (4) *horticulture*, (5) *intensive agriculture* and (6) *intensive irrigated agriculture*. 126 societies are reported to have used irrigation in agriculture. Figure 3 displays the approximate location of each ethnic group and the six types of cultivation. Societies that used irrigation broadly cluster in Asia, Africa, particularly in the North, as well as in South America. Following the methodology developed by Alesina *et al.* (2013) and Giuliano and Nunn (2017), I link historic groups to the spatial distribution of ethnicities today, and compute population-weighted averages of ancestral characteristics for contemporary societies. In

[21] Economists have used the *Ethnographic Atlas* recently to study historical characteristics of populations and their impact on modern outcomes (e.g. Gennaioli and Rainer, 2007; Nunn and Wantchekon, 2011; Michalopoulos and Papaioannou, 2013). Sampling dates of groups range from the before 1500 to 1950. The data also reports geographic coordinate of the approximate location of each group.

Figure 3: Irrigation Agriculture across Ethnic Groups



Note: This figure shows irrigation use across ethnic groups of the Ethnographic Atlas.

particular, most African ethnic groups are merged to the *Map of Ethnic Boundaries* constructed by Murdock; groups outside Africa to the *Ethnologue: Languages of the World* database, which maps the spatial distribution of 7,612 languages in the world as in 2003; if no match can be found in the *Ethnologue*, I use the less detailed *Geo Referencing Ethnic Groups* (GREG) map of Weidmann et al. (2010), which includes boundaries of ethnic groups building on the Soviet Atlas Narodov Mira. Finally, for a handful of groups no match can be found in any of these, therefore I match groups to modern administrative boundaries.[22]

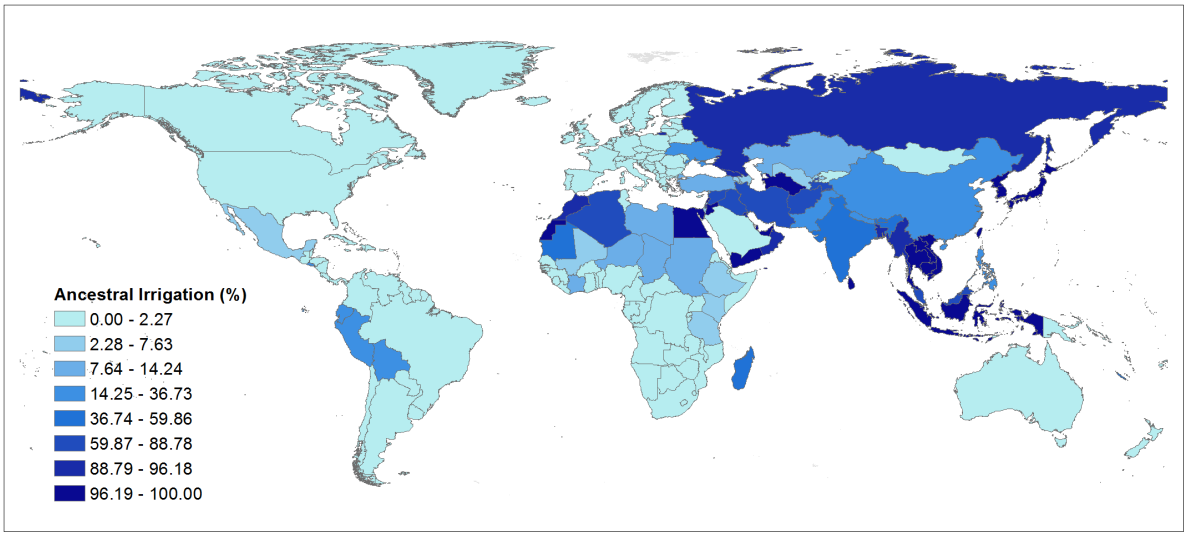
The match between historical ethnic groups and the contemporaneous distribution of ethnicities allows me to construct population-weighted averages - using population data from the *Gridded Population of the World* (GPW) shapefile - of different ancestral characteristics for current populations that reside in any administrative division on which outcome variables are measured (e.g. country or sub-national district).[23] The main variable of interest, *Ancestral Irrigation*, is therefore computed as the product between the population share of each ethnic group residing in the administrative division (e.g. country or sub-national district), times an indicator variable that takes on the value 1 if the ethnic group traditionally used irrigation, and 0 otherwise. The resulting variable gives the share of a contemporary population whose ancestors have used irrigation. Across countries it reports a mean of 23% and a standard deviation of 38%. As shown in Figure A3, the mass of the distribution is located at the extreme values of 0 and 1, and the median country has not used irrigation.[24] Figure 4 displays the country level variation in ancestral irrigation. Populations that traditionally used irrigation are primarily located in Northern and Western Africa, Asia, Russia, as well as South America. Irrigation use is low across European societies and Western offshoots in the Americas and Australia. Figure

[22] See Figure A1 for a visualization of the four different maps used and the areas that they cover. Figure A2 illustrates the matched ethnic groups exemplarily for Mexico. The basic matching procedure follows Fenske (2013) with corrections and adjustments.

[23] An important implicit assumption of this procedure is that individuals that reside within the boundaries of an ethnic group, as drawn by the maps of ethnicities today, are of this ethnicity.

[24] Cross-validating my measure of ancestral irrigation with the one based on the methodology by Alesina *et al.* (2013) shows a very strong correlations ($\rho = 0.97$). See Figure A13.

Figure 4: Ancestral Irrigation across Countries



Note: This figure shows the share of a country's population whose ancestors traditionally used irrigation.

A6 shows the distribution across sub-national districts. Since about 60% of the populations of a country either adopted irrigation completely or not at all, the variation across sub-national areas is limited.[25]

Baseline Geographic and Ethnographic Controls. To isolate the effects of irrigation from other geographic and ethnographic characteristics of historical societies, I control for a number of *baseline covariates* of irrigation. Notably, all specifications control for the overall environmental suitability for agriculture, to account for differences in traditional reliance on agriculture, that is based on data constructed by Ramankutty *et al.* (2002). Moreover, since rainfall reduces the reliance on irrigation agriculture, I control for mean levels of precipitation. Differences in the access to water sources, such as the coast or rivers (measured by the distance to the nearest coast and to the nearest major river), as well as the average altitude, might also have affected whether societies adopted irrigation or not. Finally, I control for the share of land in the tropics, since the tropics is a particularly disease-ridden area (Guernier *et al.*, 2004), and disease prevalence has been found to be a strong driver of in-group bias of populations (Fincher *et al.*, 2008). Importantly, all geographic variables are evaluated within a radius of 200km around the traditional location of ethnic groups. The ethnic-group averages are then used to compute ancestry-adjusted geographic variables for contemporary countries and regions that measure the exposure of ancestors to different geographic environments.

Furthermore, the baseline controls include several historical characteristics of ethnic groups taken from the *Ethnographic Atlas*. Motivated by the evidence of section 2.4 that showed a higher degree of centralization of institutions in irrigation societies, I control for the complexity of historical political institutions. Furthermore, as proxies for historical economic development I

[25] A number of caveats with the measure of ancestral irrigation use are aggravated on the district level. First, the methodology assigns ethnicity by the location of residence of individuals within ethnic boundaries. However, even if one assumes that spatial boundaries of ethnic groups are drawn accurately, it does not account for adjustments in spatial boundaries of ethnic groups resulting for example from migration. Second, for several regions information on ethnic groups is only available for a small fraction of the population. Since uncovered areas are coded as missing, the method produces measurement error which can be severe for sub-national regions for which only few data points are available. Consequently, most of the variation in the ancestral measure is at the macro level. A similar issue has been discussed in Alesina *et al.* (2013) in the case of ancestral plow use.

take into account the traditional type of settlement and the mean size of communities.[26] Similar to the ancestral irrigation variable, the historical characteristics of contemporaneous populations at the country or district level are population-weighted averages of the ethnographic variables.

3.2 Addressing Endogeneity

A concern with the OLS regressions is that a number of unobserved factors might have influenced whether societies adopted irrigation in the past. In particular, it is possible that populations that were more collectivist to begin with selected into using irrigation in agriculture. Furthermore, the ancestral irrigation variable that is computed from ethnographic data is susceptible to measurement error, biasing the β coefficient towards zero. To move towards identifying the causal effect of historic irrigation, I employ an instrumental variables strategy that predicts in a first stage whether societies adopted irrigation by the profitability of irrigation agriculture in a given location. Since the construction and maintenance of irrigation systems entailed costs, farmers only adopted irrigation if it was sufficiently profitable relative to other subsistence modes. The instrumental variable strategy makes use of the fact that the profitability of irrigation agriculture is determined by environmental characteristics and varies across space.

More precisely, the geographic suitability for irrigation depends on a number of local environmental characteristics, including the rainfall (or its absence), climatic and soil conditions, as well as the suitability of different crops and their water requirements. Using these geographical constraints as inputs, the Food and Agriculture Organization of the United Nations (FAO) has computed the contemporary environmental suitability for irrigation within 5-minute longitude/latitude grid cells (Fischer *et al.*, 2002). The FAO measure classifies suitability into five impact classes, where each class represents the potential increase in agricultural yields that can be obtained by fully exploiting irrigation compared to rain-fed agriculture.[27] Class (1) contains areas that are suitable for rain-fed agriculture only, class (2) includes areas where irrigation increases agricultural output by 0 - 20 %, class (3) areas where irrigation impacts output by 20 - 50 %, class (4) areas where irrigation increases output by 50 % and class (5) areas where irrigation increases output by more than 100 % (Fischer *et al.*, 2002).[28] I define land as suitable for irrigation if agricultural production increases by at least 50 %. Irrigation suitability is computed as the sum of land with impact classes (4) and (5), divided by the total land suitable for agriculture, and is relative measure of irrigation potential compared to total agricultural suitability. As for the geographical controls, suitability of irrigation is first evaluated at close proximity to the historical ethnic groups, i.e., within a radius of 200 kilometers around the centroid of each ethnic group of the *Ethnographic Atlas*. Average group-specific suitability is then aggregated to the country and district level, following the methodology described above, to derive *ancestry-adjusted suitability* measures. If not stated otherwise, measures of irrigation suitability are always population-weighted averages of the suitability in the ethnic homelands of ancestors of current

[26] Political institutions are measured by the number of jurisdictional hierarchies beyond the local community following Gennaioli and Rainer (2007) and Michalopoulos and Papaioannou (2013) and others. Settlement patterns, a proxy for historical socio-economic development, are coded on a scale from 1 to 8 and range from nomadic or fully migratory to complex settlements. The mean size of local communities, a proxy for the degree of historical urbanization, measures whether societies were organized in cities or rural communities. The variable is coded into eight classes, ranging from populations of fewer than 50, to cities of more than 50,000.

[27] The FAO assessment of irrigation suitability does not quantify the availability of water that can be used for irrigation, but assumes that "water resources of good quality are available" (Fischer *et al.*, 2002).

[28] See Figure A4 for a spatial illustration of irrigation impact classes.

populations.[29]

The validity of the identification strategy requires that irrigation suitability impacts outcomes only through its effect on the historic use of irrigation, conditional on the set of controls included. While the IV overcomes reverse causality, i.e., the adoption of irrigation by initially more collectivist groups, the main threat to the identification strategy is that irrigation suitability could be correlated with other geographic characteristics that affect outcomes through alternative channels. The base set of geographic controls take care of a great deal of potential co-variates of irrigation suitability, in particular rainfall levels, the distance to water sources and the overall suitability for agricultural production that are likely correlated with the suitability for irrigation. In the country analysis, I will address explicitly the influence of a range of other environmental covariates of suitability, such as soil and terrain constraints, arid climates, and rainfall variability. Moreover, selection into localities *suitable* for irrigation might have occurred because they are located in remote areas, or not easy to be settled, and the controls (such agricultural suitability or settlement patterns) do not adequately account for that. The country level IV estimation examines this possibility by controlling for the migration patterns of humans from Africa (i.e., the migratory distance from Addis Ababa and its square), and the timing of the Neolithic Revolution. Moreover, it assesses robustness to explicitly controlling for the - potentially endogeneous - historic importance of kin groups.

4 The Effect of Irrigation Agriculture on Collectivism

4.1 Country-Level Estimates

Ordinary Least Squares. I start by analyzing the cross-country relationship between ancestral irrigation and collectivist norms estimated by OLS in Table 1. To measure the degree of collectivism across countries, I rely on the collectivism score constructed by Hofstede *et al.* (2010).[30] Column 1 reports the unconditional effect of irrigation, that is positive and statistically significant at the 1% significance level. Conditioning on baseline geographic and ethnographic controls in column 2 increases the size of the effect of ancestral irrigation.[31] Columns 3 to 7 consider a number of historical and geographic co-variates of irrigation use and collectivism. In particular, column 3 controls for the timing of the Neolithic Revolution that measures the historical importance of farming and that has been associated with collectivism (Putterman, 2008; Olsson and Paik, 2016b). Column 4 controls for the presence of early states (Bockstette *et al.*, 2002), and column 5 accounts for the possibility that irrigation societies have historically been less democratic, as argued by (Wittfogel, 1957), by controlling for traditional democracy (Giuliano and Nunn, 2013). Column 6 uses the suitability of the environment for malaria, evaluated in the localities of ethnic groups, as a direct proxy for the disease environment that could

[29] Bentzen *et al.* (2016) were the first to use the FAO measure of irrigation suitability. My measure of irrigation suitability differs in two important ways: Rather than using only impact class 5, I find that combining classes 4 and 5 predicts ancestral irrigation - as constructed from the *Ethnographic Atlas* - better. In addition, I use an ancestry-adjusted measure of irrigation suitability rather than the unadjusted (local) country average. Parts of the empirical analysis compare the effects of the ancestry-based to the local measure of irrigation suitability.

[30] Hofstede's measure has been widely used in both the economic literature (Gorodnichenko and Roland, 2011b, 2012, 2016) and in cross-cultural research (e.g. Chiao and Blizinsky, 2010; Fincher *et al.*, 2008). It measures the degree of group integration. Hofstede originally created several indicators of national cultures from surveying IBM employees between 1967 and 1973. Later the data was enlarged using survey responses of a range of professionals from pilots to students.

[31] Table B8 replicates Table 1 reporting the coefficients of all controls.

Table 1: Irrigation and Collectivism: OLS Estimates across Countries

	Collectivism								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ancestral Irrigation	16.07***	17.25***	19.39***	18.23***	17.83***	20.52***	19.16***	18.86***	25.02***
	(4.08)	(5.35)	(6.35)	(5.89)	(5.21)	(5.70)	(5.66)	(6.70)	(6.30)
Neolithic Revolution			-0.70						3.67***
			(1.17)						(1.28)
State Antiquity				-10.79					-5.21
				(12.84)					(10.97)
Traditional Democracy					-11.78*				0.06
					(6.48)				(4.98)
Malaria Suitability						1.22**			1.71***
						(0.52)			(0.52)
Ethnic Fractionalization							23.13*		21.01**
							(11.90)		(9.83)
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	No	No	No	No	No	No	No	Yes	Yes
Observations	97	93	93	86	90	93	93	93	83
R-squared	0.07	0.36	0.37	0.40	0.37	0.39	0.40	0.63	0.72

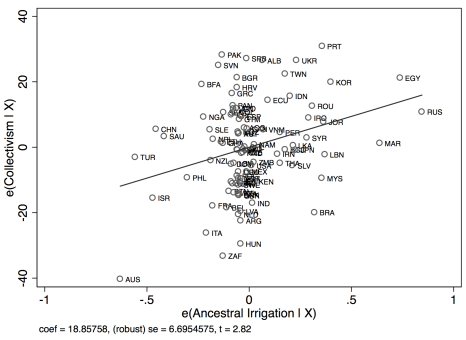
Note: OLS regressions. The unit of observation is the country. The dependent variable is the Hofstede *et al.* (2010) Index of Collectivism. Controls include baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities) that are, as well as malaria suitability, adjusted for ancestry. Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation. Region fixed effects include dummies for Europe, Africa, North America, Latin America and Caribbean, East Asia and Pacific, Central and West Asia, and South Asia. Heteroscedastic-robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

have influenced the evolution of collectivist attitudes. Column 7 takes into account differences in contemporary levels of ethnic fractionalization. Throughout all specifications, past irrigation predicts collectivism positively and significantly. Moreover, column 8 adds fixed effects for world regions to rule out that the relationship is driven by unobserved geographical and historical differences across continents, in particular dummies for countries in Europe, Africa, North America, Latin America, South Asia, East Asia and Pacific, Central and West Asia, following the classification of the World Bank. Finally, column 9 considers all controls jointly, and finds a similar positive effect of irrigation. Figure 5a illustrates the positive relationship between past irrigation and collectivism, conditional on controls and region fixed effects.

The magnitudes of the estimated effects are sizable. The unconditional effect in column 1 implies a beta coefficient of 0.27, which moves with the full set of baseline geographic and ethnographic controls, as well as region fixed effects to 0.30 (column 8). The point estimate of 18.08 in column 8 implies that increasing ancestral irrigation by one standard deviation (std.) increases the collectivism score by 6.5 percentage points. To illustrate this magnitude further,

Figure 5: Partial Regression Plots across Countries

(a) OLS



(b) First-Stage

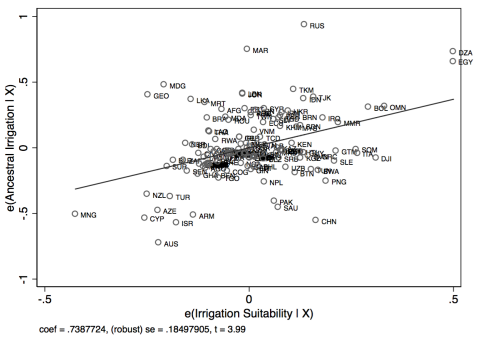


Table 2: Alternative Measures of Collectivism and Norm Rigidity

	Embededdness	Affective Autonomy	Intellectual Autonomy	In-Group Favoritism	Restraint	Social Tightness	Linguistic Individualism
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Ancestral Irrigation	0.43***	-0.37	-0.31***	0.90***	28.40***	47.56***	-0.40***
	(0.13)	(0.25)	(0.08)	(0.16)	(4.85)	(7.63)	(0.06)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	70	70	70	109	89	60	108
R-squared	0.68	0.54	0.55	0.42	0.37	0.62	0.56

Note: OLS regressions. The unit of observation is the country. Embededdness, Affective Autonomy, and Intellectual Autonomy are taken from Schwartz (1994, 2004). In-Group Favoritism is taken from Van de Vliert (2011). Restraint builds on Hofstede *et al.* (2010), and Social Tightness is taken from Uz (2015). Linguistic individualism measures subject prominence, taken from Meyer-Schwarzenberger (2015). Controls include baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities). Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation. Heteroscedastic-robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

consider a population that descend from ancestors that all practiced irrigated agriculture: If the ancestors of South Korea had not used irrigation instead of fully adopting it, its collectivism score would be 64 instead of 82, a level similar to Uruguay.

Table 2 investigates the effect of ancestral irrigation on alternative proxies of collectivist cultures. Ancestral irrigation predicts positively and significantly group embededdness, and negatively affective and intellectual autonomy, that are all based on the work by Schwartz (1994, 2004). Relatedly, in-group orientation of traditional irrigation societies is also reflected by higher levels of in-group favoritism. To enforce group conformity, irrigation societies are documented to have used punishment and rigid norms. Consistent with this observation, columns 5 and 6 show that irrigation societies have stricter social norms, i.e. they emphasize restraint, and are culturally more tight, i.e. less tolerant towards norm deviance. One concern with the Hofstede measure and the variables used in columns 1-6 is that they are measures of contemporary culture. Column 7 analyzes whether historic irrigation is also reflected in the linguistic structures of societies, as a measure of historical individualism inherited in languages. Columns 7 shows that societies that used irrigation have less individualistic language structures, i.e., their languages put more emphasize on verbs that describe relationships (topic-prominence) rather than on subjects (subject-prominence).[32] All estimated magnitudes are large and standardized beta coefficients in the range of 0.24 to 0.6 in absolute terms.

Table 3 tests the robustness of the OLS results conditional to a number of other possible confounders - some of which are measured today and therefore potentially endogeneous to the traditional use of irrigation. In particular, the adoption of irrigation, and collectivist norms, might be correlated for a number of reasons with migration patterns from the cradle of humankind in Africa. As shown in column 1, ancestral irrigation retains a significant and positive effect on collectivism conditional on a quadratic of the migratory distance from Africa (Ashraf and Galor, 2013). The effect of irrigation is also robust to controlling for the absolute latitude of the country (column 2) and differences in historical population densities measured in the year 1500 (column 3). Column 4 introduces the share of adherents to the world religions. Religion is likely endogenous to pre-existing norms and environmental conditions of irrigation agriculture. The coefficient of ancestral irrigation becomes smaller in magnitude, but remains significant at the 10% level. Columns 5 and 6 control for current institutional quality and per capita income - two other important, but endogenous, controls. In both cases, irrigation predicts collectivism

[32] See also Nisbett (2010) for a description of topic- (subject) prominence in collectivist (individualist) societies.

Table 3: Irrigation and Collectivism:
Robustness of the Country-Level Estimates

	Collectivism									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ancestral Irrigation	15.46***	14.78**	16.97**	13.41*	13.16**	15.14**	11.13**	19.76**	15.57**	17.79***
	(5.43)	(5.65)	(7.09)	(7.83)	(6.43)	(6.43)	(4.92)	(7.88)	(6.62)	(5.27)
Migratory Distance Squared	Yes									
Latitude		Yes								
Population Density 1500			Yes							
Religion				Yes						
Polity IV (1980-2014)					Yes					
(ln) Income per capita						Yes				
Perc. Natives & Europeans							Yes			
Land Gini								Yes		
Pathogens									Yes	
Soviet Dummy										Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Observations	92	92	91	93	93	92	92	80	93	93
R-squared	0.66	0.65	0.64	0.66	0.66	0.71	0.69	0.72	0.66	0.37

Note: OLS estimations. The unit of observation is the country. The dependent variable is the Hofstede *et al.* (2010) Index of Collectivism. Controls include baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities). Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation. Region fixed effects include dummies for Europe, Africa, North America, Latin America and Caribbean, East Asia and Pacific, Central and West Asia, and South Asia. Heteroscedastic-robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

positively, albeit - given the interactions between irrigation, institutions (Bentzen *et al.*, 2016), collectivism and income (Gorodnichenko and Roland, 2016) - the effects are smaller. In addition, the effect of ancestral irrigation on collectivist norms is robust to controlling for the share of Europeans and Natives by country, differences in land inequality (Bentzen *et al.*, 2016), the historical prevalence of pathogens based on Murray and Schaller (2010), as well a dummy for former Soviet countries.

Further Robustness and Additional Results. Appendix section 2.3 reports further robustness checks of the OLS specification. Table B9 shows robustness to alternative samples that focus only on the old world, drop Asia or Africa, and alternative definitions of the continent fixed effects. Table B10 controls for additional geographic characteristics, such as caloric suitability, climate zones, mean temperature, and the baseline geographic controls evaluated at the local level. Table B11 shows the effect of irrigated agriculture conditional on other pre-industrial subsistence modes, such as gathering, hunting, fishing, the use of the plow, animal husbandry, and the average intensity of agriculture. To address concerns that societies that adopted irrigation were more collectivist to start with, Table B11 also controls for the (potentially endogenous) presence of extended families. In addition, the effect of irrigation is robust to controlling for differences in class stratification and the average year when groups were observed. Finally, Tables B13 investigates the effect of ancestral irrigation on other cultural dimensions constructed by Hofstede. Consistent with the hypothesis that irrigation fostered conformity and obedience, the table shows that ancestral irrigation has a positive effect on power-distance relations, defined as the "extent to which the less powerful members of organizations and institutions (like the family) accept and expect that power is distributed unequally." Power distance is strongly correlated with collectivism ($\rho = 0.6$) and the combination of collectivism and high power distance can be defined as vertical collectivism. In addition, ancestral irrigation has only weak effects on masculinity, and does not predict uncertainty avoidance nor long-term orientation that is the focus of Galor and Özak (2016) and Figlio *et al.* (2016). Finally, in Table B14 I test whether collectivism emerged from the cultivation of rice in the past (Talhelm *et al.*, 2014). When considering

Table 4: Ancestral, Local and Contemporaneous Irrigation

	Collectivism					
	All Countries				Median Irrigated Area in 2000	
					Below	Above
	(1)	(2)	(3)	(4)	(5)	(6)
Irrigation Suitability (Ancestral)	24.84***		60.50***	72.01***	96.25***	49.01***
	(6.16)		(17.21)	(17.44)	(34.19)	(14.00)
Irrigation Suitability (Local)		10.55	-39.43**	-31.11**		
		(6.91)	(15.68)	(15.28)		
Controls	No	No	No	Yes	Yes	Yes
Region FE	No	No	No	Yes	No	No
Observations	96	97	96	93	48	45
R-squared	0.08	0.01	0.13	0.66	0.67	0.35

Note: OLS regressions. The unit of observation is the country. The dependent variable is the Hofstede *et al.* (2010) Index of Collectivism. Controls include baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities). Heteroscedastic-robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

suitability for irrigated and rain-fed rice separately, they both predict collectivism positively across countries. However, when including the two measures jointly (column 3), or taking their difference (columns 4 and 5), it appears that the association between rice and collectivism is driven by irrigation.

Ancestral, Local and Contemporaneous Irrigation. Does the effect of irrigation on collectivist norms stem from its impact on people or places? Moreover, are the effects driven by differences in the contemporary use of irrigation? Columns 1 to 4 of Table 4 compare the impact of ancestry-adjusted irrigation suitability to the unadjusted (local) country average of irrigation suitability. The ancestry-based variable measures irrigation potential in the land of the ancestors of current populations, while the local measure computes irrigation potential in the environment in which populations reside today. The results indicate that the people-based measure of irrigation suitability is the sole predictor of collectivist norms, and its impact is robust to conditioning on the local suitability for irrigation agriculture.[33] In addition, columns 5 and 6 document that past irrigation has a positive and significant effect on collectivist norms both in countries that today do, and those that do not make much use of irrigation in agriculture.[34] Together, these results indicate that i) irrigation affected culture through its impact on portable and transmittable characteristics of populations rather than places, and ii) that the effects stem from the historical rather than contemporary use of irrigated agriculture.

Two-Stage Least Squares. Table 5 reports results from instrumenting ancestral irrigation by the (ancestry-adjusted) environmental suitability for irrigation. Panel A contains the reduced-form, Panel B OLS results, and Panel C the 2SLS results. The first-stage results are reported in Table B15.[35] Column 1 reports results conditional on the base set of geographic and ethnographic controls. The 2SLS coefficient obtained is positive, significant at the 1% level and almost twice

[33] For illustration, consider Australia as an example - one of the most individualist countries. Since Australia is mostly populated by descendants from Britain that traditionally used rain-fed agriculture, the ancestral irrigation suitability variable for Australia is zero, while the local suitability for irrigation in Australia is very high (about 67 % of the soil).

[34] The median area equipped for irrigation as a fraction of total arable land in 2000 is 5%.

[35] Table B7 explores the first-stage relationship across ethnic groups of the *Ethnographic Atlas*. Consistent with the cross-country results, I find that ethnic groups in environments with a higher suitability for irrigation are significantly more likely to have adopted irrigation.

TABLE 5: IRRIGATION AND COLLECTIVISM: 2SLS ESTIMATES ACROSS COUNTRIES

	Collectivism									
	Baseline	Add. Geographical Controls						Add. Historical Controls		Region FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A - Reduced Form										
Irrigation Suitability	46.61***	52.22***	43.62***	43.16***	38.20***	37.18***	38.16***	38.01***	37.68***	49.20***
	(8.99)	(9.38)	(8.25)	(11.77)	(10.46)	(10.29)	(11.46)	(11.42)	(11.57)	(14.40)
Panel B - OLS										
Ancestral Irrigation	17.25***	17.18***	19.14***	12.35**	11.61**	12.87**	8.60*	15.77***	15.83***	18.86***
	(5.35)	(5.65)	(4.42)	(5.51)	(4.64)	(5.60)	(4.60)	(5.80)	(5.84)	(6.70)
Panel C - 2SLS										
Ancestral Irrigation	35.70***	39.14***	32.76***	33.48***	27.83***	29.19***	28.56***	31.60***	31.16***	55.91***
	(8.77)	(9.55)	(6.98)	(11.75)	(8.79)	(9.39)	(10.07)	(8.46)	(8.35)	(21.23)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Agricultural Dependence		Yes					Yes			
Soil Constraints			Yes				Yes			
Arid Climate				Yes			Yes			
Sq. of Rainfall Variability					Yes		Yes			
Terrain Constraints						Yes	Yes			
Neolithic Revolution								Yes	Yes	
Sq. of Migratory Distance								Yes	Yes	
Clan Communities									Yes	
Region FE										Yes
Observations	93	93	93	93	93	93	93	92	92	93
First Stage F-Stat	33.18	38.28	38.05	20.60	28.50	29.61	22.15	19.56	19.88	9.00

NOTE: The unit of observation is the country. The dependent variable in the Hofstede *et al.* (2010) Index of Collectivism. Controls include baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities). Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation. Region fixed effects include dummies for Europe, Africa, North America, Latin America and Caribbean, East Asia and Pacific, Central and West Asia, and South Asia. Heteroscedastic-robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The corresponding first-stage results are reported in Table B15.

as large as the one obtained from OLS. The magnitude is sizable and implies that a one std. increase in ancestral irrigation increases the collectivism score by 13 points (or 0.6 of a std.). Or, if a population such as South Koreans had not used irrigation at all, its collectivism score would be 35 points lower, and similar to Israel.

Columns 2 - 7 investigate the sensitivity of the 2SLS results to controlling for geographic characteristics that are potentially correlated with irrigation suitability. This test helps to further increase the confidence that the instrument does not affect collectivism through another channel than the adoption of irrigation. In particular, column 2 controls for the average dependency of historic societies on agriculture taken from the *Ethnographic Atlas*; column 3 for average constraints of the soil for agriculture; column 4 controls for the share of land that falls in the arid climate zone; column 5 for a quadratic in rainfall variability; and column 6 for average constraints of the terrain for agriculture. Finally, column 7 controls for all additional geographic controls jointly, which is demanding considering the small sample size. Overall, while the OLS coefficient moves quite a bit, the coefficients of the reduced-form and the 2SLS coefficients remain relatively stable when additional controls are included. If one is concerned that irrigation suitability affects collectivism through additional channels, then one expects the coefficient of the reduced-form to move considerably when controlling for additional geographical variables. Assessing coefficient stability of the reduced-form more formally following Altonji *et al.* (2005), i.e., comparing coefficients of the baseline regression in column 1 to regression with the the full set of geographic controls in column 7, implies that selection on unobservables should be 4.75 times larger than selection on observables to explain away the reduced-form effect of irrigation suitability.

Column 8 addresses the concern that selection into irrigation suitable environments could also be the result of factors that the geographical controls do not fully account for, in particular global migration patterns and the time when hunter-gatherers transitioned to sedentary agriculture.

Estimated coefficients of past irrigation are robust to the inclusion of these controls. Column 9 assesses more directly the concern that differences in the initial organization of societies made selected into irrigation suitable environments more likely, for reasons other than geography. In particular, the regression includes a control for the historic strength of kin groups measured by the presence of clan communities. Keeping in mind that this measure might be endogeneous to the practice of irrigation agriculture, the estimated coefficients of past irrigation are very similar with or without controlling for clan communities. Finally, column 10 adds region fixed effects that account for unobserved fixed characteristics of world regions and reports similar effects of past irrigation on collectivism. Throughout all specifications, the first-stage is strong with an F-Statistics between 9 and 38, and the 2SLS coefficients are about twice as large as the comparable OLS coefficient. The increase in magnitude of the 2SLS coefficient could indicate measurement error in the ancestral irrigation variable that is constructed from ethnographic data. The 2SLS coefficient of column 10 implies a 20 point increase in collectivism for a one std. increase in ancestral irrigation, which is about the difference between the Philippines (median collectivism score: 68) and Slovakia (48).

4.2 Individual-Level Estimates using Variation across Sub-National Districts

While the cross-country estimation supports the hypothesis that past irrigation favored collectivism, it cannot account for all (unobserved) country-wide factors that could have influenced the evolution of norms. This section moves from country to local variation in ancestral irrigation. It estimates the effect of past irrigation on the norms of respondents surveyed in five waves (1981-2014) of the *World Values Survey/European Values Survey (WVS/EVS)* and that are observed in sub-national districts.[36]

To measure collectivism at the individual level, I construct four dependent variables. Following previous research on conformity and autonomy, such as Kohn (1989), Inglehart *et al.* (1996) and Triandis (2001), I make use of a set of questions that ask parents about qualities that they regard as important for their children.[37] I take the mentioning of obedience and good manners as indication that parents value group conformity. I combine the two indicator variables into a single variable - labeled *Conformity* - that ranges from 0 to 2. The second variable - labeled *Conformity Scale* - subtracts indicators of autonomy, i.e., independence, and imagination, from the conformity measure. The third measure evaluates respondents' preferences for collective ownership on a scale from 1 to 10, where 1 indicates a strong preference for private ownership and 10 strong preference for state owned firms. The fourth measure asks respondents about the degree of control they have over their life, where a score of 1 indicates none at all and 10 a great deal. As reported in Table B18, on the country level collective ownership correlates most strongly with Hofstede's country measure of collectivism, followed by the conformity variable and the collectivism scale. As indicated in Table B19, the degree of control over one's life can be regarded as the sub-national equivalent of Hofstede's restraint variable.

[36]The WVS/EVS is a collection of representative national surveys conducted in almost 100 countries on all continents of the world. The first survey was conducted in 1981 and the data has been extended to a total of six waves until 2014 (WVS), and four waves until 2008 (EVS). The analysis uses the waves two to six since they contain information on the subnational districts in which respondents live. WVS/EVS districts vary in size, but most of them could be matched to the first administrative division of each country, as shown in Figure A5.

[37]Triandis (2001, p. 912), for example, notes: "In collectivist cultures, child rearing emphasizes conformity, obedience, security, and reliability; in individualist cultures, child rearing emphasizes independence, exploration, creativity, and self-reliance.".

Table 6: Irrigation and Collectivism:
Individual-Level Estimates across Sub-National Districts

	Conformity		Collectivism Scale= (Conformity-Autonomy)		Collective Ownership		Degree of Control over Life	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Reduced Form								
Irrigation Suitability	0.71***	0.30***	0.90***	0.48***	1.89***	1.11***	-0.96***	-0.69**
	(0.12)	(0.08)	(0.18)	(0.14)	(0.25)	(0.39)	(0.18)	(0.29)
Panel B: OLS								
Ancestral Irrigation	0.13***	0.09***	0.17***	0.07*	0.71***	0.42***	-0.55***	-0.27**
	(0.04)	(0.03)	(0.06)	(0.04)	(0.10)	(0.14)	(0.07)	(0.12)
Panel C: 2SLS								
Ancestral Irrigation	0.68***	0.17***	0.88***	0.28**	1.73***	1.63**	-0.89***	-1.06*
	(0.15)	(0.06)	(0.24)	(0.12)	(0.24)	(0.66)	(0.17)	(0.58)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes		Yes		Yes		Yes	
Country FE		Yes		Yes		Yes		Yes
Observations	71188	71188	69378	69378	175787	175787	191923	191923
Number of Districts	487	487	472	472	899	899	934	934
First Stage F-stat	36.97	15.75	20.97	16.36	103.10	6.86	105.29	6.13

Note: The unit of observation is the individual. Controls include individual characteristics (age, age square, gender, marriage status, and education), survey wave indicators, as well as baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities). Ancestral Irrigation measures the percentage share of a district's population whose ancestors have used irrigation. Region fixed effects in equal numbed columns include dummies for Europe, Africa, North America, Latin America and Caribbean, East Asia and Pacific, Central and West Asia, and South Asia. Odd numbered columns control for country fixed effects. Regressions are weighted by survey weights. Heteroscedastic-robust standard errors in parentheses, clustered at the sub-national district. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The individual-level analysis allows to control for individual characteristics of the respondent (i.e., age, age squared, gender, marital status, education), as well as survey wave fixed effects. Since irrigation varies across sub-national districts within a country, country fixed effects can be included. Observations are weighted using the appropriate survey weights, and standard errors are clustered at the sub-national district. The sub-national analysis uses a maximum of 191,923 individual respondents that live in up to 934 sub-national district. Estimation results are reported in Table 6.

Column 1 of Table 6 shows that past irrigation has a positive and significant effect on conformity in reduced form, OLS and 2SLS specifications. Column 2 conditions on country fixed effects that control for characteristics common to all districts within a country - such as institutions, policies and geographical features. It is important to note that this is a very demanding specification: for more than half of the countries in the sample, within-country variation in ancestral irrigation is very small or zero. Nevertheless, the estimated effects of ancestral irrigation remains highly significant, but coefficients are of considerably smaller magnitudes. The 2SLS coefficients imply that a one std. increase in ancestral irrigation increases conformity by 0.4 of a std. conditional on region fixed effects, and 0.1 of a std. conditional on country fixed effects. Considering the extreme case of full compared to no adoption of irrigation, the within-country 2SLS coefficient of column 2 implies a change of 0.17 in the conformity score - or 0.25 of a std. Columns 3 and 4 report similar effects using the collectivism scale as dependent variable. A one std. increase in past irrigation increases the conformity scale by 0.33 of a std. conditional on region fixed effects, and 0.1 of a std. conditional on country fixed effects. Columns 5 and

6 show that ancestral irrigation strongly predicts preference for communal ownership of firms rather than individual ownership. Compared to the previous results, the effect of irrigation on collective ownership is the strongest both in significance and magnitude. Increasing ancestral irrigation by one std. increases preference for government ownership by about 0.68 in absolute magnitude or 0.24 of a std. in the 2SLS specification. Translated to the country level, a magnitude of 0.68 is about the difference between Vietnam (5.15) and Finland (4.44). Finally, columns 7 and 8 document that descendants from irrigation societies have significantly less personal control over their life. The effect size is about 0.16 of a std. for a one std. increase in ancestral irrigation in the 2SLS specifications. Note that the IV looses power when country fixed effects are added in column 6 and 8, reducing the F-Stat below a value of 10. The loss in power is most likely due to the limited variation in ancestral irrigation within countries. Figures A7 and A8 illustrate graphically the positive conditional relationship between the three outcomes at the individual level and ancestral irrigation. As it can be seen from Figure A8, the introduction of country fixed effects absorbs a considerable amount of the variation in ancestral irrigation.

4.3 Heterogeneous Effects: Centralized versus Community Coordination

As described in section 2.2, coordination of water in irrigation systems could be achieved via centralized control or by means of community cooperation. Whether irrigation was managed communally or centrally might have created heterogeneous effects on norms, in particular regarding cooperation and the acceptance of authority, which this section tests for. In the absence of information on the type or scale of traditional irrigation systems, I make use of geographical constraints that have been associated with differences in the degree of coordination needed. Coordination effort, and the demand for centralized authority, increases in the size of the irrigation network (i.e., close to large water sources), and in the degree of water scarcity that makes a precise water management indispensable (i.e., in relatively drier areas) (Wittfogel, 1957). Small scale irrigation systems could be efficiently managed with communal cooperation, since monitoring of peers and agreement on shared rules is easier in small groups (Weissing and Ostrom, 1991; Bardhan, 2000). Small farmer-managed irrigation communities were more likely to develop in areas that naturally restrict the size of rivers and lead to more disperse access to water sources, in particular in rugged areas and areas of high altitude (Molle, 2004). Table 7 reports results from interacting geographic characteristics with the historical presence of irrigation, and the differential effects on norms towards authority (obedience) and cooperation (trust).[38]

Table 7 shows that the effect of irrigation on obedience is increasing with the number of large rivers (column 1) and the size of the area located in dry climates (column 4). The effect of irrigation on obedience in areas without a large river, or non-arid climates, is statistically equal to zero. Furthermore, irrigation in rugged environments (column 2), in higher altitudes (column 3) or in environments with more rainfall (column 5) goes along with a reduced preference for norms towards authority. Correspondingly, irrigation in proximity to large rivers decreases cooperation. However, societies that practiced irrigation in rugged areas and uplands have relatively more trust compared to irrigation systems in flat and lowlands. This is consistent with the observation that

[38]The differentiation between obedience and cooperation dovetails with vertical and horizontal collectivism (Triandis and Gelfand, 2012). Cooperation is crucial in farmer-managed irrigation for collective action, including the maintenance of the irrigation network and the punishment of deviators. In particular, farmers need to trust others to stick to the rotation schedule and not to free-ride. Survey results by Sedana *et al.* (2014) document that in the communally managed Balinese *Subaks* more than two-thirds of farmers have high trust in others.

Table 7: Heterogenous Effects of Irrigation: Authority and Cooperation

	Obedience					Trust				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ancestral Irrigation	-0.03	0.12***	0.11***	0.01	0.14***	-0.00	-0.07***	-0.05**	-0.02	-0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
Ancestral Irrigation × No. Large River	0.15***					-0.06**				
	(0.03)					(0.02)				
Ancestral Irrigation × Ruggedness		-0.06***					0.05***			
		(0.02)					(0.01)			
Ancestral Irrigation × Altitude			-0.12***					0.05**		
			(0.04)					(0.02)		
Ancestral Irrigation × Arid Climate				0.16**					0.03	
				(0.06)					(0.05)	
Ancestral Irrigation × Mean Precipitation					-0.00***					0.00
					(0.00)					(0.00)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	192624	192624	192624	192624	192624	191923	191923	191923	191923	191923
Number of Districts	918	918	918	918	918	940	940	940	940	940

Note: The unit of observation is the individual. Controls include individual characteristics (age, age square, gender, marriage status, and education), survey wave indicator variables, geographic controls (the base set of geographic characteristics, and additionally in each regression the measure of geography that is interacted with irrigation), as well as ethnographic controls. Ancestral Irrigation measures the percentage share of a district's population whose ancestors have used irrigation. Region fixed effects include dummies for Europe, Africa, North America, Latin America and Caribbean, East Asia and Pacific, Central and West Asia, and South Asia. Regressions are weighted by survey weights. Heteroscedastic-robust standard errors in parentheses, clustered at the sub-national district. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

cooperation and communal forms of irrigation developed in more mountainous areas (Ostrom, 1990). Together, these results document that the heterogeneity that existed in water coordination is reflected in corresponding norms of vertical and horizontal collectivism.[39]

4.4 Irrigation, Collectivism and Institutional Complementarities

Past irrigation affects norms conditional on traditional and contemporary institutions, as well as country fixed effects. Nevertheless, it is possible that complementaries exist between collectivist norms and political institutions that, in turn, could have facilitated the preservation of norms in the long-run. As illustrated by Figure 2 in section 2.4, irrigation societies had more complex and centralized institutions, but were not more or less democratic. Moreover, previous research finds that collectivism affects democracy negatively (Gorodnichenko and Roland, 2015), and that irrigation societies have less democratic political institutions today (Bentzen *et al.*, 2016). A possible channel through which past irrigation influenced institutional development could be collectivist norms. Table 8 studies complementaries between norms and institutions in the context of ancestral irrigation more systematically. It reports three main results: First, the negative association between collectivism and democracy is not specific to irrigation societies, but exists also in societies that used other forms of subsistence (columns 1 to 3). Second, ancestry-based irrigation is an even better predictor of institutional quality than local irrigation suitability, even when local irrigation suitability is computed with the highest impact class such as in Bentzen *et al.* (2016) (column 4 to 7).[40] This suggests that the impact of irrigation on populations and their characteristics, such as cultural norms, that can be transmitted is important in understanding its persistent influence on institutional quality. Third, one reason why collectivism could be a mediating channel through which past irrigation affects democracy is the possibility that strong norms of group conformity reduce the likelihood of institutional

[39] It is important to note that irrigation societies display *on average* lower levels of trust compared to other forms of subsistence. Table B21 establishes a negative relationship between past irrigation and generalized trust. It also reveals that irrigation societies have higher levels of in-group trust.

[40] This result is not influenced by whether the geographic controls included are also adjusted for ancestry or not.

TABLE 8: THE CULTURALLY EMBODIED EFFECT OF IRRIGATION ON INSTITUTIONS

	Polity IV (1980-2014)							Protest Potential	
	All	Irrig.=0	Irrig.>0						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Collectivism (Hofstede)	-0.13***	-0.09***	-0.14***						
	(0.02)	(0.02)	(0.04)						
Irrigation Suitability (Ancestral)				-10.26***		-9.69***	-9.74***	-0.43***	-0.28**
				(2.46)		(3.37)	(3.36)	(0.13)	(0.12)
Irrigation Suitability (Local)					-4.99**	-0.98			
					(2.41)	(3.10)			
Irrigation Suitability Class 5 (Local)							-0.84		
							(2.97)		
Polity IV 1980 - 2014									0.01***
									(0.00)
Controls	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Observations	96	45	51	144	144	144	144	91	90
R-squared	0.24	0.38	0.16	0.63	0.60	0.63	0.63	0.49	0.56

NOTE: OLS regressions. The unit of observation is the country. The dependent variable is the Polity IV index in columns (1) to (7) and Protest Potential in columns (8) and (9). Protest potential measures citizens willingness to engage in lawful boycott, demonstrations or to sign a petition, and is constructed from survey responses of the WVS/EVS, following Nevitte (2014). Controls include baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities). Region fixed effects include dummies for Europe, Africa, North America, Latin America and Caribbean, East Asia and Pacific, Central and West Asia, and South Asia. Heteroscedastic-robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

change (Gorodnichenko and Roland, 2015). In line with this argument, I find that ancestral irrigation suitability predicts negatively the potential of populations to protest against established authorities and to engage in political action (column 8), even when controlling for contemporary regime types (column 9).

4.5 The Persistence of Collectivism among Migrants

This section tests for a pure cultural mechanism for the persistence of collectivism. I investigate intergenerational transmission of norms in European migrants that originate from very diverse backgrounds, but are exposed to a common environment in the country they live in - including the institutions, policies, and the educational system. The migrant analysis allows to hold constant this environment with the inclusion of country of residence fixed effects.

I use data from the *European Social Survey* (ESS) to test for differences in values of immigrants living in European countries. In the data it is possible to identify the countries of origin of the parents of migrants, their birth places, and whether migrants are first or second generation immigrants. I define ancestry by the common country of birth of his/her parents.[41] To measure collectivist norms, I combine five questions about the importance of different human values developed by Schwartz (2004) using principal component analysis. These questions measure the core characteristics of collectivist cultures: the importance of respect, rule following, proper behavior, modesty, and loyalty to close people. I estimate the following model:

$$Collectivism_{i,h,o} = \alpha + \beta Ancestral\ Irrigation_o + \delta X_{i,o} + \Omega_h + \varepsilon_{i,h,o} \quad (2)$$

where $Collectivism_{i,h,d}$ measures the average collectivism score of respondent i that lives in host country h and originates from country o. $Ancestral\ Irrigation_o$ measures traditional irrigation use that varies across countries of origin o. The vector $X_{i,h,o}$ includes controls for individual characteristics of the immigrant (age and its square, gender, education fixed effects,

[41] Results are robust to using only the father's or mother's country of origin, as reported in the Appendix.

marriage status and the indicator for big cities), survey wave dummies, and baseline geographic and ethnographic controls. Ω_h are location fixed effects (either host country of residence or even sub-national district of residence). Standard errors are clustered at the migrant's country of origin.

Estimation results of equation (2) are reported in Table 9. Considering 1st and 2nd generation migrants jointly in columns 1 and 2, I find that ancestral irrigation predicts collectivist norms positively and significantly in reduced form (Panel A), OLS (Panel B) and 2SLS (Panel C) specifications.[42] The effects are estimated within countries (column 1), or within the much smaller sub-national districts (column 2).[43] The instrument is strong with a first-stage F-Statistics above 10, and the estimated beta coefficient of ancestral irrigation in the 2SLS estimation of column 1 is 0.24. Column 3 and 4 report a similar positive effect of past irrigation on collectivism using only the sample of 1st generation migrants. The remaining columns 5 and 6 focus on the smaller sample of 2nd generation migrants that were born and raised in the country of residence. Again, I find that past irrigation impacts collectivist norms significantly in the 2SLS estimation. The magnitude of the coefficients are economically meaningful. The 2SLS coefficient in column 5 implies that a one std. increase in ancestral irrigation increases the principal component of collectivism by about 0.35 in absolute terms, or 0.25 of a std. A difference of 0.35 is sizable and equivalent to the difference between the average collectivism score of migrants from the Czech Republic (median collectivism) and Japan (75% percentile).[44] Tables B22 and B23 show that the results are robust to defining ancestry of migrants by either their father's or mother's country of birth. Additionally, Table B24 documents robustness of the 2SLS results to controlling for home country characteristics, in particular income, institutions, and ethnic fractionalization.

While Table 9 documents that parts of collectivist norms are transmitted over time, external factors might amplify or hinder its persistence. To investigate heterogeneous effects of transmission, I analyze in a sample of 2nd generation migrants how characteristics of the country of residence interact with the traditional use of irrigation by ancestors. Focusing on 2nd generation migrants mitigates parts of the concerns about the endogenous sorting of migrants on country characteristics. Moreover, 2nd generation migrants are particularly well suited for studying the influence of external factors, since they were growing up in the country of residence and were subject to its characteristics from birth on. Appendix Table B25 shows coefficients of the interaction terms between ancestral irrigation and host country characteristics, conditional on host and home country fixed effects.[45] Neither the quality of institutions in the host country, nor average income per capita, nor local culture measured by host country collectivism interact with past irrigation significantly. The effect of ancestral irrigation on collectivism, however, is significantly larger in 2nd generation migrants that were raised in places with a relatively higher degree of ethnic fractionalization, and reduced in migrants that live in countries with more generous public spending on old age security. The first result implies that in-group orientation is stronger when the number of groups is larger. The second result implies that an increase in public spending for

[42] The conditional OLS relationship between collectivism and ancestral relationship is illustrated in Figure A9.

[43] The sample size is reduced for regressions with sub-national districts because only waves 5 and 6 of the ESS have a consistent classification of sub-national regions.

[44] The increase in the effect between first and second generation migrants is most likely due to the smaller size of the sample of 2nd generation migrants. Similarly, when adding sub-national fixed effects the sample sizes decrease, while the estimated coefficients of ancestral irrigation increase.

[45] Very similar results to the ones reported in Table B25 are found when interacting irrigation suitability - instead of ancestral irrigation - with host country characteristics, as shown in Table B26.

TABLE 9: CULTURAL TRANSMISSION OF COLLECTIVISM IN EUROPEAN MIGRANTS

	Collectivism					
	All Migrants		1st Generation		2nd Generation	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Reduced Form						
Irrigation Suitability	0.66***	0.89***	0.70***	0.80***	0.57***	1.04***
	(0.12)	(0.14)	(0.13)	(0.14)	(0.16)	(0.27)
Panel B: OLS						
Ancestral Irrigation	0.15**	0.20***	0.17***	0.17**	0.06	0.30**
	(0.06)	(0.07)	(0.06)	(0.07)	(0.09)	(0.12)
Panel C: 2SLS						
Ancestral Irrigation	0.85***	1.01***	0.80***	0.83***	0.97**	1.45***
	(0.27)	(0.24)	(0.24)	(0.19)	(0.45)	(0.44)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes		Yes		Yes	
Sub-National District FE		Yes		Yes		Yes
Observations	17950	8549	13632	6411	4312	2136
R-squared	0.05	0.09	0.06	0.10	0.07	0.17
No. Origin Countries	153	145	152	142	110	101
First Stage F-Stat	11.03	16.54	14.48	22.04	7.11	11.01

NOTE: The unit of observation is an European immigrant. The dependent variable collectivism is the principal component of respect, loyalty, rule following, proper behavior, and modesty. Controls include individual characteristics (age, gender, marriage status, education, city type), baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities), as well as survey wave indicator variables. Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation in the immigrant's parents' country of birth. The odd numbered columns control for country of residence fixed effects, the even numbered columns control for sub-national district of residence fixed effects. Heteroscedastic-robust standard errors in parentheses, clustered at the country of origin. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

elderly gives parents less incentives to instill obedience and loyalty in children. This is consistent with the observation that in collectivist societies welfare is traditionally group-based, and parents have an interest in restricting children's autonomy in order to assure their loyalty to the family (Friedlmeier *et al.*, 2005; Greif, 2006; Greif and Tabellini, 2017). Finally, the size of the community with shared ancestry affects the transmission of collectivism positively. This could indicate that collectivism is transmitted horizontally among peers. While these interactions do not necessarily allow a causal interpretation, they suggest that the persistence of collectivism is influenced by external factors and policies.[46]

5 Irrigation Agriculture and Long-Run Technological Divergence

I now turn to analyzing the long-run effects of irrigation agriculture on innovation and occupational selection.

5.1 Innovation at the Country Level

Table 10 shows that ancestral irrigation has a strong negative effect on scientific productivity across countries, measured by the average per capita number of scientific articles between 2000 -

[46] In addition to values, Table B27 studies differential preferences for in-group marriage of 2nd generation US migrants as an outcome measure of collectivist cultures. If irrigation strengthened group identification, then this could be reflected in a stronger preference to marry with members of the same group. Using data from the Current Population Survey (CPS) March Supplement (1994-2016), Table B27 show an increase in the likelihood of an endogamous marriage by between 4% to 11% for a one std. deviation increase in ancestral irrigation in the 2SLS estimation.

Table 10: Irrigation and Scientific Productivity: Country-Level Estimates

	Scientific articles (per 1,000 people)										
	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	IV	IV	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Ancestral Irrigation	-0.24***	-0.30***	-0.36***	-0.41***	-0.30***	-0.30***	-0.23***	-0.27**	-0.65***	-0.71***	-0.57**
	(0.06)	(0.07)	(0.10)	(0.11)	(0.09)	(0.09)	(0.08)	(0.11)	(0.16)	(0.22)	(0.29)
Neolithic Revolution				-0.05**							
				(0.03)							
Traditional Democracy				0.06							
				(0.10)							
State Antiquity				0.39**							
				(0.17)							
Polity IV (2000 - 2010)					0.02***						
					(0.01)						
(ln) Income per capita						0.16***					
						(0.03)					
Agriculture (% of GDP)							-0.10*				
							(0.05)				
Industry (% of GDP)							-0.10*				
							(0.05)				
Services (% of GDP)							-0.09*				
							(0.05)				
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Additional Geography								Yes			Yes
Region FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Observations	162	150	150	132	143	146	142	150	150	150	150
R-squared	0.04	0.38	0.62	0.65	0.66	0.70	0.67	0.67	0.31	0.59	0.64
First Stage F-Stat									52.31	16.27	9.36

Note: The unit of observation is the country. The dependent variable is the average number of articles produced annually between 2000-2010 per 1,000 inhabitants. Controls include baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities). Additional geographical controls are dependency on agriculture, soil constraints, arid climate, precipitation variability and square, as well as terrain constraints. Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation. Region fixed effects include dummies for Europe, Africa, North America, Latin America and Caribbean, East Asia and Pacific, Central and West Asia, and South Asia. Heteroscedastic-robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

2010.[47] The estimated negative coefficient is highly significant, robust to controlling for baseline controls and region fixed effects, and a host of other country-wide characteristics such as the timing of the Neolithic Revolution, traditional democracy and state antiquity, as well as contemporary institutional quality. Moreover, past irrigation continues to affect scientific productivity even conditional on average per capita incomes (column 6), and the sectoral composition of countries today (column 7). Controlling for the contribution of each sector to GDP addresses the possibility that traditional irrigation societies became locked into agricultural production.[48] Column 8 adds additional geographical controls, including soil and terrain constraints, agricultural dependency, arid climate, and a square in rainfall variability. The OLS estimates indicate that a one std. increase in ancestral irrigation reduces scientific productivity by between 0.19 and 0.30 of std, which is about half the effect of institutions and per capita incomes. Columns 9 - 11 estimate 2SLS coefficients. Conditional on base controls (column 9), regional fixed effects (column 10), and additional geographic controls (column 11), the IV coefficients are negative and significant, and about twice as large as the comparable OLS coefficients.[49] For instance, the IV coefficient of column 10 implies that a one std. increase in past irrigation would decrease the average number of articles per one thousand people by 0.27 in absolute terms or 0.6 of a std. To illustrate the magnitudes further, imagine that the population of South Korea had not

[47] While scientific output does not measure directly innovation, it is highly correlated with other measures of technological progress, for example the technology index constructed by Comin *et al.* (2010), with $\rho = 0.88$.

[48] Figure A10 displays the cross-country relationship between ancestral irrigation and innovation conditional on geographic and ethnographic controls, as well as region fixed effects.

[49] Table B28 show robustness of the OLS results to additional country controls, including religion and migratory distance, while Table B29 shows that the IV results are robust to including institutions and average incomes.

used irrigation in the past, then its current scientific output would double and be similar to the scientific productivity of Canada. The scientific output of China would increase by 250%. Conversely, if Americans descended from populations that traditionally used irrigation, the US research output would only be 38% of its actual level today.

Importantly, Table B30 demonstrates that the effect of irrigation works through people's cultural ancestry rather than place-specific characteristics: Irrigation suitability that is ancestry-based predicts technology today negatively and significantly, even controlling for local suitability, thereby lending further support to the hypothesis that past irrigation affects current technology through its effects on societies' culture. In addition, Table B30 reports that past irrigation also affects an alternative measure of contemporary technology constructed by Comin *et al.* (2010).

5.2 Sub-National Innovation

To alleviate concerns that the association between historic irrigation and innovation today is driven by unobserved country-wide characteristics, I examine whether the same relationship can be found on the sub-national level. Since data on sub-national innovative activities encompassing the world does not exist, I collect a novel dataset that measures scientific productivity for 1,893 cities located in 158 countries. To this end, I extracted the yearly number of scientific publications per city for the years 2000 - 2010 from the "ISI Web of Science". The sample choice of cities follows the consideration that it should maximize the geographical coverage within countries, but also take into account the importance of cities. I therefore include cities in the sample that are either the capitals of first-level administrative regions or countries, and supplement the sample with cities that are not capitals, but that have a population (measured for the metropolitan region) of larger than 500,000 inhabitants. I assign ethnographic data to cities using their location, i.e., I match cities directly to the polygons that indicate the locations of contemporaneous ethnic groups. In total, the sample encompasses 1,893 cities that could be merged to ethnographic information, and for which the full set of baseline controls is available. As shown in Figure A11, the sample of cities covers a wide geographic area. I estimate the following model:

$$Articles_{i,e,c} = \alpha + \beta Irrigation_e + \gamma X_{i,e} + \lambda_c + \epsilon_{i,e,c} \tag{3}$$

where i denotes cities, e ethnic groups, and c countries. $Articles_{i,e,c}$ measures the average number of articles per 1,000 people. $Irrigation_e$ is an indicator that measures whether the majority ethnic group of city i traditionally used irrigation. $X_{i,e}$ is the set of baseline controls that varies across ethnic groups and λ_c are country fixed effects.

I estimate equation (3) by OLS. In addition, since the outcome variable is highly skewed - many cities have little or no scientific activity - I also estimate Poisson maximum likelihood (ML) regressions, following Wooldridge (2002). I refrain from the IV estimation, since the instrument does not predict ancestral irrigation significantly within countries in this sample. To better account for local unobserved heterogeneity across cities, I use as alternative identification strategy a geographic matching estimator that compares "treated" and "untreated" cities in close proximity. Cities are matched two its two closest neighbors on location (longitude and latitude) and the entire set of baseline controls. The estimation is conducted in two samples: a sample that contains all cities ("full"), and a second samples of 882 cities in 54 countries that only includes countries that have variation in ancestral irrigation ("restricted").

TABLE 11: IRRIGATION AND SCIENTIFIC PRODUCTIVITY: CITY-LEVEL ESTIMATES

	Scientific articles (per 1,000 people)								
							Geographic Matching		
	OLS	OLS	OLS	Poisson ML	OLS	Poisson ML	Location & Controls		+ Country FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ancestral Irrigation	-0.99***	-0.21**	-0.20**	-0.84***	-0.21*	-0.92**			
	(0.23)	(0.10)	(0.10)	(0.29)	(0.11)	(0.36)			
Country Capital			1.46***	1.31***	1.39**	1.35***			
			(0.53)	(0.21)	(0.63)	(0.37)			
Region Capital			1.15*	0.95***	1.39*	1.26***			
			(0.59)	(0.18)	(0.78)	(0.08)			
SATT							-0.50***	-0.67***	-0.27**
							(0.15)	(0.22)	(0.13)
Controls	Yes	Yes	Yes	Yes	Yes	Yes			
Country FE	No	Yes	Yes	Yes	Yes	Yes			
Sample	Full	Full	Full	Full	Restricted	Restricted	Full	Restricted	Restricted
Observations	1893	1893	1893	1893	882	882	1893	882	882
Number of Countries	158	158	158	158	54	54			
R-squared	0.11	0.32	0.34		0.27				

NOTE: The unit of observation is a city. The dependent variable is the average number of articles per year and 1,000 inhabitants between 2000-2010. Controls include baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities). Ancestral Irrigation measures whether the majority ethnic group of the city used irrigation. SATT indicates the treatment effect for the treated from a nearest neighbor matching for the 2 nearest matches. Heteroscedastic-robust standard errors in parentheses, clustered at the country level in columns 1 - 4. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 11 reveals that ancestral irrigation has a negative and statistically significant effect on innovative activities across cities. Across countries, the effect size is about 1 article less per 1,000 inhabitants. Within-countries, the coefficient of column 2 implies a reduction of 0.21 articles per 1,000 inhabitants, which amounts to a decrease of 25% of the mean or 8% of a std. The coefficient is robust to controlling for whether the city is the country or region capital (column 3). Column 4 estimates Poisson ML regressions and finds a larger impact: evaluated at the mean (the average number of articles is 0.88), the coefficient of ancestral irrigation implies a reduction of 0.72 articles per one thousand people. The estimated effects on innovation are very similar in the restricted sample (columns 5 and 6). Finally, the nearest neighborhood matching that compares cities to its two closest neighbors, reported in columns 7 - 9, confirm the negative impact of irrigation on city level innovation. The average treatment effect suggests a reduction in articles by between 0.5 to 0.67 per 1,000 inhabitants allowing for matches across country borders (columns 7 and 8), and a reduction of 0.27 if cities are matched within countries (column 9).

5.3 Technological Divergence from 1000BC to 2000AD

Societies that used irrigation in the past are less innovative today. Yet, historical accounts and the ethnographic evidence presented in Figure 2 suggest a higher degree of specialization and technological progress in these societies in pre-industrial times (Mann, 1986; Mokyr, 1992). Using data on technological advancement for the period 1000BC to 2000AD constructed by Comin *et al.* (2010), I examine in this subsection whether irrigation societies were systematically falling behind technologically, and approximately when this reversal occurred.

Table 12 documents that irrigation societies had a higher level of technology throughout the pre-1500 period.[50] The differences in technological progress are significant and large - beta coefficients range from 0.29 in 1000 BC, to 0.23 in 0 AD to 0.17 in 1500 AD - but they are

[50]Since the main independent variables are adjusted for ancestry, I also use the ancestry adjusted measures of technological sophistication from Comin *et al.* (2010) that take into account post 1500 population flows This fixes the population composition of countries to its contemporary composition.

Table 12: Irrigation and Long-Run Technological Reversal across Nations

	Technological Progress (Ancestry Adjusted)			
	1000 BC	0 AD	1500 AD	2000 AD
	(1)	(2)	(3)	(4)
Ancestral Irrigation	0.203*	0.119***	0.140**	-0.117***
	(0.116)	(0.043)	(0.064)	(0.044)
Controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Observations	102	122	110	119
R-squared	0.38	0.40	0.79	0.72

Note: OLS regressions. The unit of observation is the country. The dependent variable is the index of technological progress taken from Comin *et al.* (2010). Controls include baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities). Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation. Region fixed effects include dummies for Europe, Africa, North America, Latin America and Caribbean, East Asia and Pacific, Central and West Asia, and South Asia. Heteroscedastic-robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

decreasing over time.[51] Column 4 reveals a reversal in technological progress in the period between 1500 to 2000: a one std. larger share of ancestral irrigation predicts a 0.21 of a std. reduction in current technology, a result that mirrors the negative effects of ancestral irrigation on scientific output documented previously.[52]

To take into account fixed country features, and to estimate the change in technology over time, Table 13 reports results from estimating fixed-effect models similar to a differences-in-differences (DiD) estimations of the following form:

$$Technology_{c,t} = \gamma_t + \delta_c + \beta post1500 * Irrigation_c + \lambda post1500 * X_c + \epsilon_{c,t} \quad (4)$$

where $Technology_{c,t}$ is the ancestral technology index for country c at time period t, γ_t are time fixed (1000 BC, 0 AD, 1500 AD, 2000 AD), δ_c denotes country fixed effects that control for country-wide time invariant factors, and $post1500 * Irrigation_c$ is an interaction term between the post 1500 period and either the environmental suitability for irrigation, or the measure of ancestral irrigation. All regressions control for the interaction between the time invariant geographic and ethnographic controls with the post-1500 dummy ($post1500 * X_c$). The estimation thereby takes into account a potential time-varying effect of past institutional complexity.

Column 1 of Table 13 shows that countries with environments more suitable for irrigation experienced a decline in technological progress after 1500. The same negative reduced-form relationship between technology and irrigation in the post-1500 period is found considering the ancestry-adjusted irrigation suitability (column 2). Importantly, comparing the effect of local irrigation suitability against ancestral irrigation suitability in column 3, the decline in technology is again driven by the suitability measure that takes into account ancestry of populations. This

[51] Importantly, measures of past technology computed by Comin *et al.* (2010) do not include the adoption of irrigation, but whether agriculture existed, how important it was, and whether the plow was used.

[52] As an alternative way to test for the reversal of technology, Table B31 replicates the estimation in Comin *et al.* (2010), regressing current technology on historical levels of technology, but adding an interaction between historical technological sophistication and ancestral irrigation. Consistent with the findings in Comin *et al.* (2010), technological progress is highly persistent. In addition, the table shows a negative and significant interaction term between past technology and irrigation, suggesting that irrigation societies could not benefit from their early head start. Table B31 also illustrates that the people-based measure of irrigation suitability drives this reversal. Technological progress in 1500 interacts significantly and negatively with irrigation suitability that is adjusted for ancestry - even when controlling for the interaction of technology with (ancestry adjusted) overall agricultural suitability (Litina, 2016).

TABLE 13: IRRIGATION AND LONG-RUN TECHNOLOGICAL REVERSAL: DID ESTIMATES

	Technology (Ancestry Adjusted)							
	RF	RF	RF	OLS	IV	RF	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Irrigation Suitability (Local) × Post 1500	-0.27***		0.03					
	(0.09)		(0.10)					
Irrigation Suitability (Ancestral) × Post 1500		-0.46***	-0.48***					
		(0.07)	(0.08)					
Ancestral Irrigation × Post 1500				-0.29***	-0.43***			
				(0.04)	(0.07)			
Irrigation Suitability (Ancestral) × 0 AD						-0.08		
						(0.15)		
Irrigation Suitability (Ancestral) × 1500 AD						-0.23**		
						(0.11)		
Irrigation Suitability (Ancestral) × 2000 AD						-0.53***		
						(0.15)		
Ancestral Irrigation × 0 AD							-0.10	-0.08
							(0.08)	(0.13)
Ancestral Irrigation × 1500 AD							-0.10	-0.19*
							(0.08)	(0.10)
Ancestral Irrigation × 2000 AD							-0.35***	-0.48***
							(0.09)	(0.14)
Controls × Post 1500	Yes	Yes	Yes	Yes	Yes			
Controls × Year FE						Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	453	453	453	453	451	453	453	451
R-squared	0.58	0.61	0.61	0.61	0.60	0.72	0.72	0.71
First Stage F-Stat					63.39			13.90

NOTE: The unit of observation is the country-period. The dependent variable is the index of technological progress between 1000BC and 2000 taken from Comin *et al.* (2010). Controls are baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities) and interacted with the Post 1500 dummy, or period dummies. Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation. Heteroscedastic-robust standard errors clustered at the country level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

implies that irrigation environments influenced technological progress over time mostly through its effect on (cultural) characteristics of populations. Finally, columns 4 and 5 document that the actual adoption of irrigation by a countries' ancestors has similar negative influence on technology, in both OLS and IV regressions. The magnitudes of the IV coefficient imply that a std. increase in ancestral irrigation led to a decline in technology of 0.57 of a std. after 1500.[53] Going beyond the pre/post 1500 comparison, columns 6 - 8 report coefficients from flexible estimates that interact ancestral irrigation with each time period. The results document that the decrease of technology in irrigation societies starts around the year 1500.[54]

Together, the evidence presented implies that irrigation societies were technologically more advanced in Malthusian economies - in which agriculture is the dominant form of production and technological progress is generally slow - but were falling behind in the modern stage of development characterized by sustained technological growth. These reduced-form results are open to various interpretations. One possible explanation is that collectivist norms were beneficial in some stages of development, but lost their benefits in others. This cultural explanation is consistent with the effects of irrigation on norms documented above. It is also supported by the fact that ancestry-based measures of irrigation are the best predictors of innovation. Rather than through a change in local institutional conditions, such as property rights, the effect of irrigation

[53]Table B32 document robustness to restricting the sample to the old world, to countries outside Europe, and to controlling for interactions of continental dummies with the pre-and post 1500 periods.

[54]The coefficient from the flexible estimations are illustrated in Figure A12. A number of robustness checks validate further the observed reversal of technology in irrigation societies. Tables B33 and B34 show results from DiD and flexible estimates using the technology index that is unadjusted for migration, while Tables B35 and B36 estimates computed excluding historical military technology that is not part of the current technology index. Table B37 addresses concerns about the data quality in very early periods, and restricts the panel to the periods 1500 and 2000.

seems to work through its influence on people.

Group conformity allowed societies to coordinate agricultural production more efficiently thereby increasing productivity, which was channeled primarily into higher population growth. Since larger populations imply a larger stock of ideas, and better coordination an easier adoption of available technologies, irrigation societies had a technological advantage in the agricultural stage of development. The takeoff from agriculture to the modern growth regime, however, relied on a rapid and large increase in innovations (Mokyr, 1992). Conformist behavior posed an important hindrance to technological creativity, leading eventually to a reversal in technology between individualist and collectivist societies.

5.4 Individual-Level Innovativeness of US Migrants

To further test for a cultural mechanism behind the association between irrigation and innovation - isolated from other, e.g. institutional, explanations - I analyze the effect of past irrigation on the degree of innovativeness of US migrants. I draw on data from the *National Survey of College Graduates* (NSCG) which is a a longitude biennial survey that samples college graduates living in the US.[55] The NCGS allows to identify ancestry by respondents' countries of birth. As before, studying migrants has the advantage that they imported their cultural beliefs to an external environment which can be held constant, i.e., concerns about differences in laws or regulations varying across countries that affect patenting and innovation are mitigated.

I use the 2003 wave of the survey - the only publicly available wave that asks respondents about patenting and research productivity - to assess the the innovative output of college graduates. Respondents to which a patent has been granted, and those with at least one scientific publication (e.g. a scientific article, a book, or a contributed article to a conference) are identified with an indicator variable. As a second measure of scientific output, I count the number of publications per respondent. The publication measures dovetail with the country measures of scientific productivity used above. Moreover, I create an indicator variable that identifies respondents that attended a professional meeting or conference.

Table 14 reports regression results of reduced-form, OLS, and IV regressions, that control for individual characteristics of the respondent (age, age squared, gender, marital status, age at arrival in US, educational attainment, indicators for the level of education completed in the US, current log salary and its square), the base set of geographic and ethnographic controls, and fixed effects for US macro-regions.[56] Overall, individuals that originate from populations that used irrigation are significantly less likely to be innovative, and generate lower levels of scientific output. The estimated 2SLS coefficients are up to twice as large as OLS coefficients. For example, the 2SLS coefficient in column 1 suggests that a one std. increase in traditional irrigation decreases the probability of patenting by about 0.8%, which given the sample average of patenting of 0.04 implies a 18% increase of the sample mean. According to column 2, the likelihood of a publication is reduced by 3%, or 10% of the sample mean, for a one std. increase in ancestral irrigation. In addition, a one std. increase in traditional irrigation translates into about one publication less which is equal to about 24% of the sample mean (or 0.08 of a std.). This effect is slightly larger than the gender difference in the number of publications (0.8 less

[55] The survey evaluates economic outcomes of college graduates, particular those in science and engineering. It has been used in previously in the migration-innovation literature by Hunt and Gauthier-Loiselle (2010).

[56] The regression model is similar to the migrant analysis using ESS data in equation (3). Macro-regions are the smallest administrative level on which respondents are observed.

TABLE 14: IRRIGATION AND INDIVIDUAL-LEVEL INNOVATIVENESS OF US MIGRANTS

	Patent Granted	Any Publication	No. of Publications	Conference Attendance	Important in Job: Independence
	(1)	(2)	(3)	(4)	(5)
Panel A: Reduced Form					
Irrigation Suitability	-0.02**	-0.08*	-2.34**	-0.11***	-0.20***
	(0.01)	(0.04)	(0.92)	(0.03)	(0.06)
Panel B: OLS					
Ancestral Irrigation	-0.01*	-0.06***	-1.23**	-0.08***	-0.08**
	(0.01)	(0.02)	(0.53)	(0.01)	(0.03)
Panel C: 2SLS					
Ancestral Irrigation	-0.02**	-0.08**	-2.43**	-0.10***	-0.21**
	(0.01)	(0.04)	(1.12)	(0.03)	(0.10)
Controls	Yes	Yes	Yes	Yes	Yes
Observations	16127	16127	16127	32948	52029
R-squared	0.05	0.15	0.07	0.13	0.05
Number of Countries	121	121	121	130	128
First Stage F-stat	9.91	9.91	9.91	17.47	8.84

NOTE: The unit of observation is an US immigrant. Controls include individual characteristics (age, gender, marriage status, age at arrival in the US, dummies for bachelor, professional and postgraduate degrees, indicators for the level of education that was completed in the US, log salary and its square, and survey wave fixed effects), baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities), as well as US macro-region fixed effects. Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation. Heteroscedastic-robust standard errors in parentheses clustered at the country of origin. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

publications for female), but smaller than the effect of having a degree above a bachelors (4 publications less for individuals with only a BA degree). Column 4 shows that ancestral irrigation also has a negative effect on the likelihood that the respondent attended a conference.

The results are consistent with the hypothesis that past irrigation continues to influence individual-level innovation by having affected portable cultural traits of individuals. Moreover, the data allows to examine directly a cultural mechanism. In the waves 1993-2013 of the survey, respondents were asked about their desired job characteristics, ranging from advancement opportunities, to security, to payment, and independence. I take the mentioning of independence as indication for a cultural preference for individualism. Column 5 shows that individuals from irrigation societies are significantly less likely to mention independence as important job characteristic. The coefficient implies that a one std. increase in ancestral irrigation reduces the likelihood that respondents mention independence as an important job characteristic by 8%, or about 0.13 of a std. Interestingly, Table B41 shows that the negative effect of irrigation on innovativeness is mitigated in migrants that completed some part of their education in the US. While the effect does not allow a causal interpretation, it suggests that education could play an important role in overcoming deep-rooted beliefs and calls for further investigation.[57]

[57]In addition, Table B38 shows that OLS results are robust to controlling for home country controls such as institutional quality, ethnic fractionalization and income. Table B39 documents robustness of the OLS relationship controlling for additional respondent characteristics. Finally, Table B40 studies the effect of ancestral irrigation on the entire set of desired job characteristics. Preferences of descendants from irrigation societies are not different regarding societal contribution, security, payment, location, benefits and advancement opportunities of their job.

Table 15: Irrigation and Patterns of Job Specialization across Countries

	Routine			Independent			Manual		
	OLS	OLS	IV	OLS	OLS	IV	OLS	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ancestral Irrigation	0.649***	0.529**	0.691**	-0.883***	-0.858***	-1.085***	0.310	0.179	0.299
	(0.204)	(0.203)	(0.272)	(0.234)	(0.234)	(0.366)	(0.239)	(0.218)	(0.280)
(ln) Income per capita		-0.336***	-0.321***		0.142	0.121		-0.414***	-0.404***
		(0.100)	(0.084)		(0.122)	(0.113)		(0.123)	(0.110)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	71	70	70	71	70	70	71	70	70
R-squared	0.27	0.36	0.36	0.28	0.30	0.29	0.25	0.36	0.36
First Stage F-Stat	.	.	92.29	.	.	92.29	.	.	92.29

Note: The unit of observation is the country. All dependent variables are country averages computed from survey responses of the World Values Survey/European Values Survey. Routine measures whether tasks are mostly routine, Independent measures the degree of independence of tasks, and Manual measures where tasks are mostly manual versus cognitive. Controls include baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities). Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation. Heteroscedastic-robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5.5 Occupational Specialization of Countries and US Migrants

Besides its influence on innovation, historic irrigation might have shaped the global patterns of occupational specialization. As it discouraged personal autonomy and favored a culture of obedience and rule following, descendants of irrigation societies might be less apt for occupations that require independence. They potentially have, however, a comparative advantage in jobs that require to follow procedures and routines.

I study the association between ancestral irrigation and patterns of specialization in two layers. Table 15 reports the effects of ancestral irrigation on occupational specialization across nations, using country-averages from the WVS/EVS surveys. It shows a positive impact of ancestral irrigation on the degree of routine intensity of jobs (column 1), even when controlling for income differences across countries (column 2), and when instrumenting ancestral irrigation by its suitability (column 3). The IV coefficient suggests that a one std. increase in past irrigation increases the degree of routine intensity by 0.4 of a std. Columns 4 - 6 report a similar but negative effect of past irrigation on the degree of independence of occupations that is equally large. While the results seem to support the hypothesis of higher routine intensity in irrigation societies, is possible that these differences are explained by a higher share of manual jobs in populations that traditionally relied on irrigation. As shown in columns 7 - 9, the share of manual labor is not significantly different. Together, these findings imply that parts of the observed patterns of occupational specialization across countries can be traced back to pre-industrial agriculture. They also mirror the results of Campante and Chor (2017) who document a two-way relationship between attitudes towards obedience at the workplace and the degree of routine intensity of jobs.

Occupational choices of 2nd generation US migrants, surveyed in the *Current Population Survey* (1994-2016), provide a second layer of evidence and allows to isolate the culturally embodied effect of past irrigation. I classify migrants' occupations into routine, and non-routine tasks, using the O*Net job classifications. The degree of routine-intensity is the average of a job's degree of repetition, accuracy and structure, following Acemoglu and Autor (2011). As an alternative measure, I look at jobs that reflect a preference for following procedures and routines set by an authority (labeled conventional occupations). In addition, I use a job's degree of innovation, independence, and freedom of decision to measure to which extent occupations involve non-routine (or innovative) tasks. Table 16 investigates job characteristics of high-skilled 2nd

Table 16: Irrigation and Job Tasks of US Migrants

	Unweighted			Weights: Same N		
	Routine	Conventional	Non-Routine (Innovative)	Routine	Conventional	Non-Routine (Innovative)
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Reduced Form						
Irrigation Suitability	0.06*	0.03	-0.03	0.21***	1.37***	-0.15**
	(0.04)	(0.12)	(0.03)	(0.07)	(0.35)	(0.06)
Panel B: OLS						
Ancestral Irrigation	0.03**	0.15**	-0.03***	0.07**	0.32**	-0.09***
	(0.01)	(0.06)	(0.01)	(0.03)	(0.12)	(0.03)
Panel C: 2SLS						
Ancestral Irrigation	0.09	0.04	-0.04	0.16***	1.08***	-0.12**
	(0.08)	(0.17)	(0.05)	(0.06)	(0.34)	(0.05)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14779	14779	14779	14779	14779	14779
R-squared	0.06	0.08	0.11	0.09	0.12	0.16
No. Origin Countries	100	100	100	100	100	100
First Stage F-Stat	4.10	4.10	4.10	40.65	40.65	40.65

Note: The unit of observation is an 2nd generation US immigrant that graduated from college. Controls include individual characteristics (age, gender, dummies for bachelor, professional and postgraduate degrees, log family income and its square, and survey wave fixed effects), baseline geographic & ethnographic controls (agricultural suitability, average rainfall, distance to coast and rivers, land in tropical climate, average altitude, political complexity, settlement types and mean size of local communities), as well as US State fixed effects. Ancestral Irrigation measures the percentage share of a country's population whose ancestors have used irrigation. Heteroscedastic-robust standard errors in parentheses clustered at the country of origin. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

generation migrants, defined as having at least a college degree. OLS results, reported in Panel B and columns 1 - 3, imply that migrants that descend from societies that used irrigation agriculture are today more likely to work in occupations that are intensive in routine tasks (column 1); they have a stronger preference for conventional jobs (column 2); and they are less likely to work in non-routine occupations (column 3) - conditional on their educational level. However, some of the reduced form (Panel A) and 2SLS coefficients (Panel C) - while having the expected sign - are not significantly different from zero.

The weak first stage could be a result of the unbalancedness of the sample of migrants that gives large weights to some countries of origin. For example, out of the 14779 observations, 2419 are Mexican (16%), while only 51 descend from France (0.3 %). Therefore, in columns 4 to 6 I reestimate the models weighing the regression in such a way that each country of origin receives equal weight. This weighting scheme is equivalent to taking the mean for each country and using each country of origin as a single observation.[58] In the weighted regressions, coefficients still have the expected sign, but are now significantly different from zero, and the instrument is strong (F-Stat 40.65). The magnitudes of the IV coefficients range between 0.15 to 0.25 of a std. for a one std. increase in past irrigation.[59,60]

[58] Weights for each country c are computed as $w_c = \frac{1}{N_c}$, where N_c is the total number of surveyed individuals from country c.

[59] In addition, Table B42 shows that OLS results are robust to controlling for home country GDP; Table B43 reports similar results for the sample of all (1st and 2nd gen) migrants; Table B44 shows that similar, but weaker effects are found in migrants with all education levels.

[60] For related evidence see also Gorodnichenko and Roland (2016), who find that individuals from individualistic societies have a higher likelihood to be scientists or researchers.

6 Conclusion

This paper tests whether the need for collective efforts in irrigation agriculture favored the evolution of collectivist cultures that stress group conformity over individual autonomy. Combining ethnographic data with modern outcomes, I find that societies that used irrigation in the past have stronger collectivist norms today, across countries, individuals in sub-national districts and European migrants: among others, they value obedience, conformity, collective ownership, modesty, respect and loyalty. To address the endogeneity inherent in the historical adoption of irrigation, I use environmental characteristics that constrained its use as instrumental variable. Results from two-stay-least-square estimations similarly show that historic irrigation increased collectivism.

The positive effects of historic irrigation on attitudes towards obedience are greater in environments with large rivers and arid climates, corroborating the prominent hypothesis of Wittfogel (1957). Regarding the mechanisms of persistence, my findings suggest that historic irrigation affects collectivism through lasting change in transmittable cultural norms. In fact, migrants from irrigation societies continue to hold more collectivist beliefs, even when living outside their country of origin. At the same time, ancestry-based measures of irrigation suitability predict political institutions today. This suggests that collectivist cultural norms are not independent of the institutional environment. Interactions between culture and institutions could plausibly result in a stronger acceptance of authoritarian governments that perpetuate collectivist norms.

The second part of the paper documents a reversal in technological progress over time. While societies that used irrigation were technologically well-advanced before 1500, in the centuries that follow I find a consistent negative effect of pre-industrial irrigation on level of innovation. The fact that this result is driven by ancestry-based measures of irrigation, and that migrants descended from irrigation societies are less innovative, both point at a cultural channel. This implies that the effect of culture on economic outcomes varies in different stages of development. Norms of group conformity, beneficial for coordination in agricultural societies, became disadvantageous for innovation in modern times. An additional economic outcome likely affected by differential attitudes towards independence and conformity is occupational choice. To this regard I find that historic irrigation predicts patterns of job specialization within countries and among migrants, where traditional irrigation societies have a comparative advantage in routine occupations that require obedience and rule-following.

Together, my findings can help to understand the observed trajectories of technological progress and specialization of historical irrigation societies, particularly those of the Middle East and Asia. These societies were well-advanced in Malthusian times, but systematically fell behind during the Great Divergence and, even today, are characterized by low levels of progress and development. Moreover, the historical perspective of my study allows to obtain novel insights on the long-run societal consequences of technology adoption. My results suggest that the cultural change induced by the use of certain technologies might have negative effects in the long-run. Whether similar conclusions can be drawn in the context of other technologies is open for further research. Finally, my results have implications for policies aimed at increasing contemporary innovation and growth in traditional irrigation societies. Policy interventions, such as education policies that aim to counter deep-rooted conformist beliefs and foster creativity - while maintaining the positive effects of in-group solidarity - may be especially valuable.

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