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CENTRO STUDI LUCA D'AGLIANO
DEVELOPMENT STUDIES WORKING PAPERS

N. 486

May 2023
This version: August 2024

Qanats

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ISSN 2282-5452

Qanats*

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Abstract

Qanats – traditional small-scale Persian irrigation systems – required a complex of cooperative local institutions for their construction and maintenance. We show that these institutions produced a (local) culture of cooperation in Iran that persists to the present day when qanats are no longer of economic value. We use unique geo-coded data on qanat coordinates in Iran and build an IV using grid-level geological preconditions necessary for construction and functioning of qanats: gently-sloped terrains and intermediate clay content. Qanats impact positively activities of cooperatives, as well as pervasiveness of credit institutions and trust in neighbours, particularly under stable climatic conditions.

Keywords: Cooperation culture, Irrigation, Cooperatives, Qanat, Social capital, Trade routes, Persistence

JEL classification codes: Z10, N55, O13, O53, Q13, Q15, D70

[*] We are grateful to Mostafa Beshkar, Pietro Biroli, Jean-Paul Carvalho, Marco Casari, Bruno Conte, Metin Cosgel, Mathieu Couttenier, Arcangelo Dimico, José-Antonio Espín-Sánchez, Murat Genc, Gunes Gokman, Sophie Hatte, Anastasia Litina, Sinong Ma, Stelios Michalopoulos, Petros Milionis, David Nagy, Christopher Paik, Giovanni Prarolo, Jared Rubin, Philipp Sadowski, Philip Sauré, Tommaso Sonno, Daniel Sturm, and the seminar participants at Queen's University Belfast, University of Bologna, Goethe University Frankfurt, Johannes Gutenberg University of Mainz, Lyon ENS, Indiana University Bloomington, University of Otago (Dunedin), Institute of Social and Economic Research (University of Osaka), University of Tokyo, Nagoya University, International University of Japan, and those at ASREC Europe 2022 (University of Notre Dame, London), ASREC (Harvard University), and the Workshop on Culture, Institutions, and Development (Lund) for insightful discussions.

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1 Introduction

The *qanat* is a very peculiar small-scale irrigation technology invented by ancient Persians to bring groundwater to surface in arid regions using gravitational force. A novel feature of the qanat that distinguishes it from irrigation systems associated with despotocracies is its local-scale nature and the fact that it did not require central organization or infrastructure. Collective action is instead an intrinsic feature of qanats essential for their construction, maintenance, operation, water allocation, and knowledge transfer (Labbaf Khaneiki, 2019). Given the intense level of cooperation required for its existence, the irrigation system could contribute to the efficient and sustainable functioning of locally-governed institutions (Ostrom, 1990). Institutions may persist in the form of culture to manage groundwater and subsist under water scarcity over time (Boyd and Richerson, 1988), resulting in higher levels of social capital observed today (Putnam et al., 1994; Guiso et al., 2016).

We study the role of historical qanats and their preservation across generations on the origins and persistence of cooperation in local communities within Iran. The characteristics of the technology necessitated a high degree of cooperation, the culture of which was cemented in the society and can be observed today, even if these institutions are no longer present and qanats are of no economic value. Iran is an especially interesting setting for this question as there has been very little long-term development work on Iran, it is a weakly (formally) institutionalized environment, and because the institutions we emphasize are non-religious in nature. We further show that qanats were not built in areas suitable for agriculture and were not a driver of population, cities, and economic activity in later periods. Historically, a more stable environment across generation and proximity to ancient trade routes contributed to the persistence of the qanat-induced cooperation culture.

We construct for the first time unique geo-localized data on the locations of all documented qanats in Iran $(40,850)$ and digitize provincial data on cooperatives organizations for each Iranian sub-province. The use of data on the actual location of qanats allows us to exclude mechanical irrigation activities not related to cooperation. Dividing Iran into around $21,000$ virtual sub-provinces, we also build a novel instrumental variable using clay content and terrain slope at each grid, to exogenously measure the impact of qanats on the extent of social capital today. While the technical features of qanats require a gentle slope for every topology to enable construction and operation, an adequate clay content of soil is essential to assure feasibility of digging wells and tunnels, as well as groundwater storage and flow. Using this information helps identify the effect of qanat-induced cooperation not only through the demand for this technology, but also conditions that make its existence feasible. To further meet the exclusion restrictions and single out the role of qanats on social capital, we also look at cooperatives unrelated to agriculture in other sectors.

Qanats were first built around 1000 B.C. when the technology was invented in the Central Iranian Plateau to bring mountain groundwater to arid plains (Forbes, 1964; Goblot, 1979). Over centuries and under different empires, thousands of qanat communities were established in Persia. Interestingly, Iran was the only country in the region where ancient big empires were not formed near big rivers. During the Achaemenid period ($550-330$ B.C.), taxes were waved for those who cultivated arid lands through qanats (Alemohammadi and Gharari, 2010).[1] Citizens were granted rights to access qanat water in exchange for participating in their maintenance under the Sassanids at $224-651$ A.D. (Perikhanian and Garsoian, 1997). Centuries later, qanats were used to reestablish commerce by supplying water to caravanserais built along the Silk Road during the Safavids rule in $1501-1736$ A.D. (Salek, 2019). The unique irrigation technology persisted and new qanats continued to be constructed in more recent history. In the 1960's the qanat system provided up to 75% of the water used in Iran and irrigated about half of the land under cultivation (Wulff, 1968). Following the Islamic revolution of 1979, farmers were also allowed to dig water wells to encourage self-reliance and the expansion of agriculture. Over the period of $1980-2000$, more than $14,000$ qanats dried out due to falling water tables related to the extraction of $500,000$ pumped wells around the country (Delavari-Edalat and Abdi, 2017).

The distinct feature of qanats that induces stronger norms of cooperation is the relatively small scale of the irrigation system making it more of a self-governed common pool resource institution (Olson, 1965; Weissing and Ostrom, 1991; Bardhan, 2000).[2] The mechanism is different from capital-intensive large irrigation projects for which economies of scale and the centralization of power were crucial factors (Wittfogel, 1957; Bentzen et al., 2017). A notable example of the latter is the historical event studied in Allen and Heldring (2022) that involves the col-

[1] The Achaemenid kings also promoted qanat construction by continuing to grant the profit for five generations to people who dug them (Potts, 1990).

[2] This is conceptually parallel to medium-size canals in Mediterranean Spain, which worked as self-governing institutions that persisted by creating incentives for people to resolve conflict over scarce resources and collaborate (Donna and Espín-Sánchez, 2021; Espín-Sánchez and Gil-Guirado, 2022).

lapse of the cradle of civilization in Mesopotamia as a result of the inability of the state to provide vital support for producing the necessary long-distance canals and maintain irrigation systems. The Persian empire instead relied on small-scale qanats, constructed and organized by local groups privately without the state playing a role in their operation (Lambton, 1989; Bulliet, 2009). In addition, the relatively small amount of output and the frequency of its use in a vast area made massive public ownership or management unfeasible, relating qanats more to the human niche for local necessity (Beaumont, 1989; Wilkinson et al., 2012).

Turning to the outcome variable, cooperatives are a recent phenomenon in Iran that emerged as the most important institutional arrangement of the 1960s land reform (Lambton, 1969). These entities are membership-based entrepreneurial organizations with a multi-stakeholder nature and inclusive governance that together promote a sense of social responsibility and community embeddedness (Borzaga and Sforzi, 2014).[3] They are generally considered social capital-based organizations, with trust and cooperation as their basic pillars.[4] It is therefore easier to build cooperative enterprises where the level of social capital is high as it requires cooperation, collective action, generalized trust, social norms, and solidarity value within the community (Evers, 2001).

To investigate whether the proposed transmission of the cooperation culture manifests itself into particular forms of social structure in terms of religion or general morality, we measure the altruistic societal norms using data on the pervasiveness of Islamic microfinance institutions granting interest-free loans without a collateral known as *Qard al-Hasan* (benevolent loans), mainly for welfare purposes, at each sub-province of Iran. One can think of this variable as the ultimate outcome of cooperation, with the results strikingly confirming our hypothesis. Finally, we test our argument directly on the level of trust in local communities today. The 7th wave of the World Value Survey (WVS) provides information on the location, where the survey was conducted. After geo-locating the 133 towns in which the questionnaire was distributed, we count the number of qanats within a 50 km buffer and find that a higher number of qanats explicitly result in greater trust within a neighbourhood. We conclude that the cooperation culture that stemmed from qanats has led to a wider spread of local charity-based establishments and more trust, both of which are representatives of social capital today.

[3] Cooperative enterprises are defined by the international cooperative alliance an "autonomous association of persons united voluntarily to meet their common economic, social, and cultural needs and aspirations through a jointly-owned, and democratically-controlled enterprise."

[4] See Valentinov (2004); Hogeland (2006); Spognardi (2019); Kustepeli et al. (2020).

The rest of the analysis is organized as follows. Section 2 reviews literature on irrigation and culture and data used. Section 3 provides relevant technical details about the qanat technology. Section 4 presents the data collected and created for the paper. Section 5 reports the baseline results. Section 6 describes our instrumental approach and extends our baseline findings. Section 7 discusses persistence and historical channels that can play a role in the process. Section 8 concludes.

2 Literature on Irrigation and Culture

Studies on irrigation have a long history and are dispersed across disciplines, particularly in social-anthropological and engineering literature, a recent strand of economic research has aimed to explore the link between irrigation and culture. Due to the lack of consistent data on historical irrigation, studies on the impact of irrigation on social capital across countries have relied on geographical and climatic variables to identify societies that were based on irrigation. One of the first works in this branch is Litina (2016). Using climate and soil data from Ramankutty et al. (2002), she shows that poor land productivity predisposed regions to the need for cooperation to create agricultural infrastructure, and this in turn led to the evolution of the social capital (trust) required for industrial development in later periods. To link land suitability to social capital with the scope of cooperation as the mediating factor, she uses data from Aquastat-FAO to calculate an index for irrigation potential as the extent of land that becomes marginally suitable for cultivation under both rain-fed and irrigation conditions over the fraction of total arable land under only rain-fed conditions, i.e. boost in the productivity of land due to irrigation. Litina (2016) also uses the fraction of irrigated land over arable land for a sample of non-industrial countries in 1900 from Freydank and Siebert (2008) to measure actual irrigation as a proxy for the result of cooperation.

A series of contemporaneous papers introduced an alternative methodology of applying climate data to study the origins, evolution, and persistence of culture and institutions. They use data from FAO Global Agro-Ecological Zones (GAEZ) that divides the world into grid cells that fall under five categories of irrigation impact defined as $\frac{\text{max. attainable yields from irrigated agriculture}}{\text{max. attainable yields from rain-fed agriculture}} - 1$. The irrigation potential is then found by calculating the proportion of the high impact areas to total land suitable for agriculture (Fischer et al., 2002). This is supplemented by pre-modern data on historical irrigation use from the Ethnographic Atlas Murdock (1967) to reveal information on whether a society had agriculture and if it actually used irrigation. It is then possible to locate the homeland and population of each ethnic group and compute the average ancestral irrigation for each country, while always controlling for agricultural suitability to consider differences in reliance on agriculture.

Bentzen et al. (2017) used this approach to argue that wealthy landlords who could afford the fixed cost of building large-scale irrigation systems in areas of severe water scarcity could monopolize water and thus agriculture. They used this bargaining power against tenants in need of water with little outside option to oppose democracy. Buggle (2020) instead showed that the need for cooperation within groups in irrigation systems of pre-industrial agriculture shaped a collectivist culture that has led to less innovative societies today. The cooperation factor is shown to be particularly strong for small-scale irrigation networks. Their results suggest that the findings in Bentzen et al. (2017) regarding the historical presence of a landed elite absorbs only a part of the effect of irrigation on contemporary cultural traits. Buggle and Durante (2021) add by showing that trust developed in pre-industrial times as a result of experiences of cooperation aimed at coping with climatic risk (fluctuation) for subsistence in regions that were primarily agricultural. Giuliano and Nunn (2021) further demonstrate that culture is more likely to persist in areas with a similar environment across generations using data from Mann et al. (2009) to measure intergenerational climate instability. More broadly, our study also relates to a series of literature that shows how past events and economic institutions may have long-lasting effects on trust and cooperation today.[5]

A key issue with modern data on actual irrigation obtained from FAO's Aquastat database is that it includes modern mechanized irrigation systems based on diesel and electric motors that no longer embody the intrinsic cooperative nature of traditional qanats.[6] Historical data on actual irrigation is also not without its own drawbacks, as 85% of the observations in 1900 are estimated by qualitative backward extrapolation of modern data. While GAEZ is a better source of global data on irrigation, its coverage has limits for a disaggregated regional analysis. For example, according to irrigation potential proxy calculated at global level in previous literature, most of Iran scores the maximum for irrigation potential, lead-

[5] See, e.g., Nunn and Wantchekon (2011), Galor and Özak (2016), Dell et al. (2018), Suesse and Wolf (2020), and Karaja and Rubin (2022). Nunn (2014) provides a complete survey of literature on the role of cultural traits and formal institutions in historical persistence by showing how the latter can evolve into culture and persist in the long run when institutions no longer exist.

[6] Mustafa and Qazi (2007) for example compared the traditional irrigation system in Pakistan to the modern electric tube-well system and discussed how only the former prompted cooperation to institute self-regulating groundwater management.

ing to missing information on variations within the country.[7] While irrigation can be viewed as a channel for the formation of political institutions like autocracies at country level, a regional-level within-country analysis allows to highlight its relationship with culture in pre-modern societies. The actual data on qanats and cooperatives makes it possible to study the link between the cooperation required by this complex traditional irrigation technology and social capital today at the local level.

3 Technical Features of Qanats

The qanat irrigation systems are almost entirely found in zones with total precipitation between 100 and 300 mm, where cultivation is impossible without irrigation (Beaumont, 1985). Iran principally consists of arid and semi-arid regions. Its key source of water comes from precipitation, which is annually less than a third of the global average and distributed sporadically throughout the country. The water resources are available in plains near mountainous ranges, but lack in plains throughout the rest of the country (i.e. center, south, east). To get an initial picture of the pervasiveness and the size of qanats, 15 million acres of cultivated land (somewhere between one-third to one-half of the irrigated area in Iran) were watered by around 37,500 qanats, 21,000 of which were in full operation and 16,500 used but in need of repair (English, 1968). This sums up to around 270,000 kilometers of underground tunnels dug to transport water, 7 times as long as the Equator and roughly three-quarters of the distance to the moon. However, the majority of qanats are individually small in scale and run less than 5 km (Manuel et al., 2018; Beaumont, 1968), making it a rare occasion for them to extend across sub-provinces.

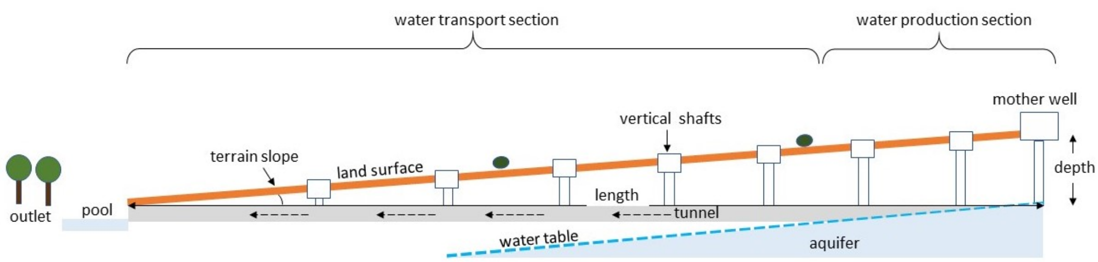


Figure 1: Profile of a typical Qanat

[7]Interestingly, it can also be seen in Espín-Sánchez et al. (2023) that Iran exhibits significant within-country variation in rainfall hazard rates with respect to the rest of the world, encompassing regions with both positive and negative rates.

A qanat is an underground gallery that brings water from an aquifer to low elevation dry lands via gravity without requiring energy and with a balanced natural inflow and outflow. It extends upslope until the water table is tapped, where groundwater is usually collected from an alluvial fan and emerges at the downslope end to supply cultivated land in an oasis. Communities generally live in a village or agricultural area around the outlet, where the water can be obtained and used for irrigation. In general, many shareholders had the right to access a qanat and the water was divided in a way that each were granted an interval to bring qanat water to their land.[8]

As depicted in Figure 1, the system comprises a water production section, where the water seeps into the part of the tunnel dug through an underground saturated area (aquifer), and a water transport section where the water flows down the tunnel and is conveyed to the earth surface. A qanat also consists of a series of vertical shafts interconnected at the bottom through the tunnel. The first and usually deepest shaft called "mother well" is sunk to a level below the groundwater table into the aquifer generally at depths of around $20-30$ m, but could go up to $90-100$ m for longer qanats. Additional shafts are dug at closely spaced intervals of $20-200$ m in a line between the groundwater recharge zone and the irrigated land to evacuate the soil and supply oxygen during digging and construction of the tunnel, and later for inspection, repair and cleaning purposes (Cressey, 1958).

The length and the gradient of qanats are calculated by traditional methods requiring skills that have been handed down by qanat workers over generations. The gradient must allow the water to flow at an appropriate speed not to leave excessive sediment and at the same time not so rapid to wash away the tunnel and cause erosion (Yazdi and Labbaf Khaneiki, 2017). The tunnel must therefore be gently sloped, nearly horizontal. A minimum terrain slope is necessary for the tunnel to eventually intersect with the surface. A high surface slope would also make it technically unfeasible to dig a mother well deep enough to meet the groundwater table. Among geological attributes, the clay content of soil is a crucial feature that accounts for the feasibility of qanats. Clay makes it easier to dig wells in contrast to other types of terrain (e.g. rocks), considering that qanats were mostly constructed in the pre-modern era. It also makes it possible to keep and convey water through the tunnel as opposed to other types of soil like sand.

[8]Qanat users had an irrigation right to a certain number of hours in each turn, which also depended on the crop and soil conditions. For example, for wheat and barley which are the most common crops in Iran, the interval was 12 days. For some qanats in Kerman, fragmentation has progressed so far that the smallest owner has rights to only 30 seconds of water once every 12 days (English, 1968).

However, an excessive clay content also reduces consistency and makes it difficult to dig tunnels. As it will be made clear in the rest of the analysis, we exploit these features of qanats as an instrumental variable to predict the prevalence of qanats across sub-provinces of Iran.

4 Data

Our primary data source consists of the geographic coordinates of 40,850 qanats, collected by the Agriculture Ministry of Iran as part of a project to document all water resources and existing qanats across the country. Figure 2 depicts the coordinates of qanats throughout Iran. Figure 3 zooms into Iran's Northwestern province of East Azerbaijan adjacent to Lake Urumiyeh, the area where qanats originated from, sketching the number of qanats in each sub-province to demonstrate how qanats are distributed unevenly across the province.[9]

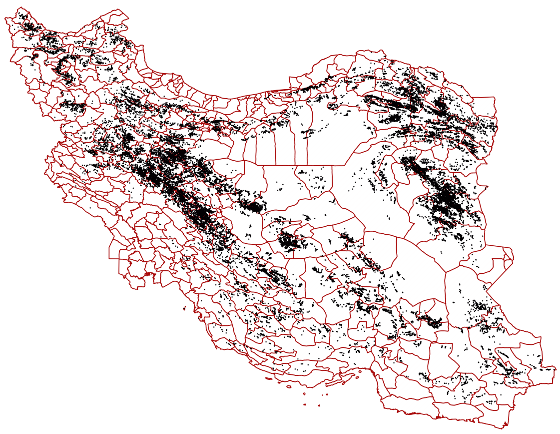


Figure 2: Qanat coordinates across Iran

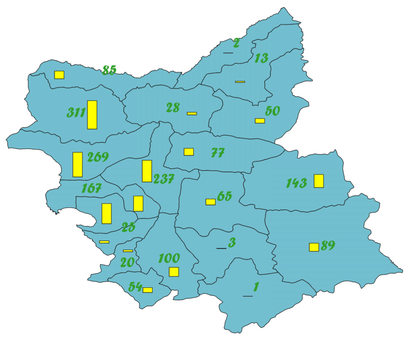


Figure 3: Distribution of Qanats in the Province of East Azerbaijan

The data on cooperative companies is collected from Iran's Ministry of Cooperatives, Labour, and Social Welfare annual reports called "statistical yearbook" (*Amarnameh* in Persian) provided for 31 provinces of Iran. As our analysis requires information at a finer level of disaggregation, we obtained data for each of the 429 sub-provinces separately from the respective province office. We have digitized the data for year 2018, which is the last year available at the time of this study. We are primarily interested in the number of cooperatives, but also

[9]Qanats later diffused to major parts of the Iranian Western highland (Zagros), Hamedan (the capital of Medes), Persepolis (the ancient capital of Persia), and the great Iranian deserts, especially in Esfahan, Yazd, Kerman and Semnan (Kamiar, 1983).

use the share of active members over population. There were a total of $93,584$ active cooperatives in Iran with 9.56 million members (11.6% of the population), contributing approximately 7% to the GDP. Cooperative companies are defined in agriculture, industries, construction, housing, services, transportation, among others, with 17% classified as agricultural and 13% under the industrial sector. As an example, Figure 4 corresponds to Figure 3 and shows the proportion of agriculture and industrial cooperatives in the sub-provinces of East Azerbaijan.

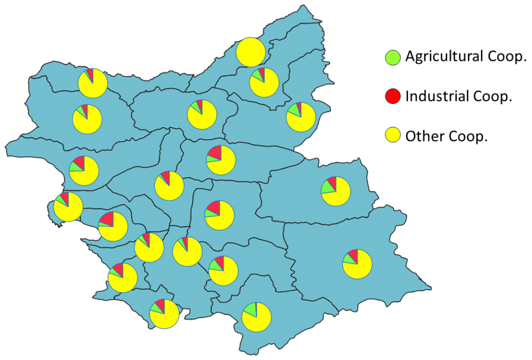
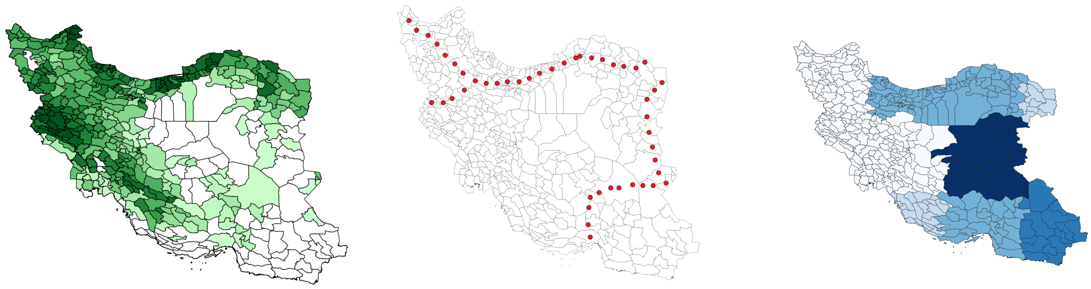


Figure 4: Cooperative companies in the province of East Azerbaijan

We supplement this with census data collected in 2016 by the Statistical Center of Iran to account for sub-province demographic characteristics, namely data on population, literacy and employment rates. To isolate the impact of qanats from the overall environmental suitability for agriculture, we consider for a handful of geographic and climatic covariates that might also affect the adoption of irrigation through technology, agriculture, or economic activity. These include factors such as access to other water sources (rivers, dams, lakes), maximum temperature, average precipitation, elevation, ruggedness, slope, and clay content. We use different *raster* data to account for these variables. The raster layers for climatological variables are obtained from the WorldClim2 dataset (Fick and Hijmans, 2017). Other types of geographic data used are in the form of shape files. The map of Iran and every sub-province comes from the worldwide spatial database GADM (gadm.org). Figure A.1.1 in the Appendix illustrates each of these geographical attributes for Iran.

We next turn to variables that could have historically affected culture and development in each region within Iran. We add population density to account for the effect of the development of agglomerated urban communities on the existence of cooperative enterprises. For an approximation of historic and pre-historic population, we refer to grid-level archaeological data from Mayshar et al. (2022), using the number of archaeological sites that existed prior to 476 A.D. derived from ancientlocations.net for the former, and the number of post-Neolithic sites and settlements from Whitehouse and Whitehouse (1975) for the latter. For our purpose, it is also essential to always control for land suitability, which could in itself be the explanatory variable for our outcome of interest. Settlements and thereby cooperatives may simply be born in areas with appropriate conditions for cultivation. To account for this, we extract data on land suitability for agriculture in Iran from Ramankutty et al. (2002), which provides information on land quality at a resolution of 0.5 by 0.5 decimal degrees based on the probability that a particular grid cell may be cultivated. The distribution of agricultural suitability across Iran can be observed in the first panel of Figure 5. A darker shade represents more fertile areas for cultivation of all crops.



Land Suitability | Historical Trade Routes | Climate Anomalies

Figure 5: Historical Controls

To test other potential historical factors we take data on ancient trade routes constructed in Michalopoulos et al. (2018), and use the oldest period available (600 A.D.) most likely to be exogenous. This accounts mainly for the silk road and its branches across Iran. To test climate-related cultural persistence, we also use data from Giuliano and Nunn (2021) on the variability of average temperature anomaly or average drought severity in standard deviations over seventy 20-year generations from 500 − 1900 A.D. for 5 by 5 degrees grid cells.[10] Cropping Iran out of the worldwide data and adapting to the sub-province level, the country can be ranked into five degrees of climatic instability illustrated in the third panel of Figure 5, with the lightest region being the most stable and the darkest representing the most disruptive climate patterns.[11] Table 1 provides the summary statistics of our key variable of interests at the sub-province level across Iran. A more detailed description of all data utilized in the paper can be found in Appendix A.2.

[10] We are indebted to Paola Giuliano and Nathan Nunn for providing us with the data.
[11] There is no data available for an area containing some of the Eastern sub-provinces of Iran.

Variable	Source	Obs.	mean	sd	min	max
Qanats	Iranian ministry of agriculture	429	1.27	3.05	0.0	38.8
Agri. coop.	Iranian min. of coop., labour & social welfare	413	0.38	0.46	0.0	3.9
Ind. coop.	Iranian min. of coop., labour & social welfare	416	0.21	0.25	0.0	2.3
Total coop.	Iranian min. of coop., labour & social welfare	402	1.67	1.43	0.0	10.6
Agr. coop. member	Iranian min. of coop., labour & social welfare	407	5.11	7.19	0.0	67.2
Islamic credit inst.	Islamic Economy Organization (www.seei.ir)	429	0.01	0.02	0.0	0.1
Arch. sites	Mayshar et al. (2022): anchientlocations.net	429	1.27	1.73	0.0	9.5
Prehist. arch. ruins	Mayshar et al. (2022): Whitehouse & Whitehouse (1975)	422	0.69	1.10	0.0	8.0
Prehist. settlements	Mayshar et al. (2022): Whitehouse & Whitehouse (1975)	422	0.63	1.07	0.0	8.0
Pop. dens.	Authors	422	158.88	633.18	1.3	8380.1
Slope	gadm.org	429	3.77	2.65	0.0	13.3
Clay content	soilgrids.org	429	293.56	64.17	150.1	469.1
Elevation	gadm.org	429	1282.23	666.36	-25.2	2664.3
Ruggedness	gadm.org	429	53.68	38.72	0.7	188.0
Annual precip.	Worldclim2 (Hick and Hijmans, 2017)	429	301.10	195.16	54.2	1442.4
Max temp.	Worldclim2 (Hick and Hijmans, 2017)	429	37.00	4.10	28.0	46.7
Water sources	mapcruzin.com	429	0.66	0.48	0.0	1.0
Land suit.	Ramankutty et al. (2002)	428	0.14	0.16	0.0	0.8
Dist. trade	Michalopoulos et al. (2018)	429	178.09	153.65	3.5	616.8
Clim. instab.	Giuliano and Nunn (2021)	415	0.20	0.08	0.1	0.4
Trust in neighbours	World Value Survey (Wave 7)	1,493	0.79	0.41	0	1

Table 1: Summary Statistics

5 Empirical Strategy and Baseline Results

5.1 Baseline Specification

We begin by examining the relationship between qanats and cooperation in our baseline regressions using the following Ordinary Least Squares (OLS) specification:

$$CC_i = \alpha_i + \beta.Q_i + \delta X_i + \varepsilon_i, \tag{1}$$

where CC_i indicates the degree of cooperation culture in sub-province i proxied by the number of cooperative companies, Q_i represents the measure of qanats at sub-province i, X_i includes the control variables for each sub-province, and ε_i is the error term. In all upcoming regressions we normalize the dependent variable by population (*per* 1000) to appropriately adjust for differences in population across the sub-provinces of Iran. The measure of qanats in each sub-province is standardized in a similar manner as more populated areas that have a higher number of qanats may affect the dependent variable for reasons other those argued in the paper. However, we show in Appendix A.3 that our results remain strongly robust when using the count of qanats without normalization. We initially conduct the analysis for cooperative companies in the agriculture sector. We then replicate the exercise for industrial and total cooperatives across all sectors (in Table 4) to avoid capturing a potential mechanical relationship between the presence of qanats and agricultural production.

5.2 OLS Results

Our baseline regressions estimate how the presence of traditional irrigation systems impacts the establishment of agricultural cooperative. The results are displayed in Table 2. Our coefficient of interest, qanats, is positive and statistically significant at 1% level. The effect is stable with a consistent coefficient after adding the geographic and demographic covariates in columns (2) and (3), respectively.[12] We have included available census controls, as they could be important determinants of the extent of today's cooperative activities.[13]

	Dependent variable: Agricultural cooperatives							
								Member share
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Qanats	0.024***	0.026***	0.023***	0.023***	0.023***	0.020**	0.031***	0.307***
	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)	(0.006)	(0.110)
Center prov.			-0.203***	-0.204***	-0.206***	-0.264***	-0.216***	-3.273***
			(0.055)	(0.056)	(0.056)	(0.054)	(0.056)	(0.721)
Arch. sites			-0.022*	-0.022*	-0.024**	-0.009	-0.022*	-0.345*
			(0.011)	(0.012)	(0.011)	(0.011)	(0.012)	(0.194)
Land suit.				0.073	0.002	-0.105	-0.085	3.252
				(0.202)	(0.223)	(0.216)	(0.228)	(3.896)
Dist. trade					-0.000	0.000	-0.000	-0.004
					(0.000)	(0.000)	(0.000)	(0.003)
Clim. instab.							0.360	5.902
							(0.493)	(5.580)
constant	0.347***	-0.030	-0.000	-0.058	-0.278	0.000	-0.445	-4.956
	(0.024)	(0.329)	(0.374)	(0.382)	(0.432)	(0.019)	(0.504)	(6.900)
Geog. Controls	-	X	X	X	X	X	X	X
Census Controls	-	-	X	X	X	X	X	X
Observations	412	412	412	411	411	411	397	392
R-squared	0.03	0.04	0.07	0.07	0.07	0.06	0.09	0.07
Province FE						X		

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Dependent variable and qanats expressed per 1,000 population. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2: Qanats and the Number of Agricultural Cooperatives: OLS

We also check whether a sub-province is the capital of a province, using a dummy variable "Center prov." Qanats are used in arid or semi-arid areas in Iran and usually access to water is very limited in the region, therefore the exit options

[12] We also use a dummy for new sub-provinces to account for recent changes in the administrative divisions of Iran, as the registration of cooperatives may not have immediately been transferred to the reports of sub-provinces newly recognized as a division, underestimating the effect of qanats on the number of cooperatives.

[13] In columns (1)-(2) of Table A.3.2 in the Appendix we use our key demographic controls (literacy and employment rate) as dependent variables in place of cooperatives and show that they are not correlated with qanats. In columns (3)-(4) we further show that dropping them will leave the outcomes unaffected in our full OLS and IV specifications (column (7) of Tables 2 and 3), respectively.

or outside opportunities to meet irrigation needs are unlikely. A negative and statistically significant coefficient shows that there are less cooperative companies at the capital of each province, which contains less farms and is usually a large densely populated center of the service and financial sector in the province. This can also be interpreted based on the theories of cooperation, to reflect that more outside opportunities or exit options in bigger cities bring about less cooperative activities. Column (3) also includes our proxy for historic population, interestingly showing that regions with a greater concentration of archaeological sites exhibit a lower extent of cooperative activities today.

In column (4) we incrementally control for overall land suitability for crop cultivation. Cooperatives are not located in lands more suitable for agriculture. Being close to trade routes may have made a region attractive to settle as it enabled farmers to sell their agricultural products outside their localities.[14] Trade opportunities as such could induce trust, cooperation, or institutions, and over time lead to the formation of cooperatives. Column (5) adds distance to the nearest trade route to control for this.

In column (6) we control for province fixed effects to capture variation within each province. Interestingly, the number of qanats seems to play a pronounced role in determining the number of cooperative enterprises established within each province, with less of them operating at the province capital. In column (7) we replace province fixed effects with the climatic instability measure, which also works as a broader fixed effect encompassing several provinces. This control allows us to verify that the cultural outcome manifesting itself in cooperative activities today is not solely due to the continuity of environmental conditions, i.e. due to recurring climate shocks or the lack thereof. In our full specification, we observe that a one standard deviation higher level of the qanats measure corresponds to a 0.191 standard deviation increase in the outcome variable. Note that all specifications throughout the paper account for spatial autocorrelation of the data by using Conley-corrected standard errors at a 50 km cutoff with linear decay (Conley, 1999; Kelly, 2020).[15]

We next test the robustness of our estimates by looking at the relationship between qanats and the share of population, also rescaled per 1000, in each sub-province who are members of agricultural cooperatives. Doing so helps mitigate concerns that cooperative firms might have a larger presence alongside conventional firms in certain areas. In the absence of information about the total num-

[14] We lose one observation as there is no land suitability data for the island of Abu Musa.

[15] All results hold when increasing the radius up to 200 km.

ber of firms, the ratio of cooperative members directly signals the proportion of population who engage in cooperative activities. Such concerns are further addressed in the next subsection when exploring the correlation between qanats and economic activities measured by population density. Column (8) shows that our results remain qualitatively identical when using member share. Table A.3.1 in the Appendix reproduces the analysis using the log of the number of qanats found in each sub-province and demonstrates that our findings remain strongly robust even when not standardizing by population.

We can draw some similarities and compare our baseline framework with Beltran-Tapia (2012), who investigate the impact of historical irrigation as a proxy for pre-existing stock of social capital, on the emergence of the cooperative movement in Spain. The idea is that long-standing traditions of local cooperation facilitated the required mutual knowledge and trust through a process of collective learning to participate in such endeavours. This is derived by looking at the proportion of cooperative members over the active male agrarian population in 44 provinces. The importance of irrigation communities for each province is instead measured by looking at the proportion of agricultural land irrigated by a system of canals and *acequias*.

5.3 Population Density

A related common concern in the literature goes back to the question of development. Thinking of alternative explanations, one may suppose that qanats were built in already populated areas more suitable for cultivation, or that they may have improved agricultural productivity and resulted in a movement of people to these regions. This would prompt increased economic activity and create a more likely scenario for the establishment of cooperatives today. Although we control for land suitability throughout the analysis, to further tackle this issue we relate to several historical studies that use population density as the dependent variable to study path dependence. A key contribution in this direction is Bleakley and Lin (2012), which shows that cities today were formed in focal points where obstacles to water such as falls interrupted navigation and required portage for continued transport. Population and economic activity continued to thrive at these sites despite their role going obsolete after the advent of new transport technologies (canals, locks, railroads) and, closer to our context of qanats, the replacement of falls as sources of water power with more modern means. In the same spirit, Paik and Shahi (2023) builds on Frachetti et al. (2017) to show how locations that pass through once essential nomadic corridors in the highlands continued to be used as trade routes and formed settlements that remain densely populated today.

The alternative hypothesis that qanats played the same role by drawing population seems less relevant in our framework as qanats are more feasible and essential in rather isolated and less densely populated areas. To test this conjecture, in Table A.4.1 of the Appendix we replicate our baseline regressions from Table 2, replacing the dependent variable with population density.[16] We observe no statistically significant correlation between the presence of qanats and population density, with a negative coefficient. Qanats are not found in densely populated areas, hence they could not have resulted in more cooperatives today by fostering long-run urban development. Interestingly, one can observe a positive relationship between historical and contemporary concentration of population within provinces. Table A.4.2 of the Appendix places our historic and pre-historic population measures as dependent variable, controlling for the geographic and historical covariates. We observe a statistically significant negative correlation between qanats and all three proxies, reinforcing the idea that areas with qanats were never densely populated. Additionally, ancient settlements tend to have dwelled close to trade routes and in climatically stable regions as one would expect.

6 The Instrumental Variable

Despite the battery of controls and various robustness checks, it is important to acknowledge that the results obtained through the OLS regressions are to be interpreted with caution and the regression could be plagued with endogeneity issues, such as reverse causality concerns that agricultural cooperative companies were established to contribute the building of qanats. So far we have argued that the geographical and technical features of qanats nurtured the culture of cooperation prior to the formation of cooperatives. Once possible after the 1960s land reform, cooperative enterprises were more likely to be formed in areas with a high concentration of qanats. Our dataset allows us to make this distinction because after this juncture modern irrigation technologies such as large water dams and deep wells with electric and fuel-powered pumps were constructed to replace qanats (Allan, 2005).

Other potential unobserved factors that might have influenced the adoption of cooperative norms could include the notion that societies which built qanats

[16] We have removed population from the denominator of the *Qanats* variable as it now appears on the left hand side. Nonetheless, using our original measure produces the same outcome.

may have been more cooperative to begin with due to certain land features that are also conducive to qanats. From another perspective, cooperatives may instead serve as an alternative to markets in less developed areas. To address these issues, we devote the next part of the analysis to building a suitable instrumental variable and use it to estimate the pervasiveness of qanats in each sub-province.

6.1 Construction of the Instrumental Variable

To deal with potential endogeneity matters, we exploit variation in qanat construction induced by differences in natural features of land across sub-provinces in Iran. Local topography is a paramount factor in locating the irrigation system. We develop an instrumental variable strategy based on the geological characteristics necessary for this irrigation technology to identify the qanat variable. More precisely, geological suitability for qanats to be build and functional depends on a combination of local environmental factors, including climatic, soil and terrain characteristics. While these are the confounders for the second stage (influence of qanats on cooperation), we use a specific transformation of two key features (intermediate clay content plus a gentle slope) as a novel instrument for qanats, as alone they could not explain the emergence of different types of cooperative enterprises.

The validity of the identification strategy requires meeting the exclusion restriction that feasibility of implementing the irrigation technology impacts the outcome only through its effect on the actual use of qanats, conditional on the set of controls included. The IV built can be deemed adequate to mitigate reverse causality concerns because on the one hand the IV coefficient is sufficiently strong to guarantee its relevance, and on the other hand the specific transformation of clay content and slope help meet the exclusion restriction. These geological conditions themselves cannot directly lead to the establishment of cooperatives, unless mediated by the presence of qanats. Another threat to the identification strategy is that the irrigation technology could be correlated with other geographic characteristics as omitted variables that affect the outcome variable through alternative channels. The basic set of geographic controls cover a great deal of potential covariates of irrigation suitability, including rainfall levels, distance to water sources, and overall agricultural suitability that could particularly be correlated with the need for irrigation technology adoption.

Our IV can distinguish between two areas that can equally benefit from qanat irrigation, where the more qanat-suitable region with an adequate slope and clay content can accommodate more qanats and incite a greater scale of cooperation. The exogenous combination of the geological characteristics of land employed should help address to a great degree concerns regarding factors that may attract both qanats and cooperatives simultaneously. Importantly, the identification strategy compares qanat-suitable regions to both arid lands in need of qanats and populated fertile areas enjoying rain-fed agriculture or other forms of irrigation, that do not meet the geological requirements.

To build the instrumental variable we first use GIS tools to create grid-level data, dividing Iran to 9 km $\times$ 9 km grids summing up to around $21,000$ virtual sub-provinces. Calculating the density of qanats at each grid, Figures A.5.1 and A.5.2 in the Appendix provide a first glance of the transformation of the number of qanats in real sub-provinces to the gridded Iran. Using information about the engineering features of qanats as a benchmark, we build an interval of terrain slope and clay content to select lands most adequate for building qanats. To produce the map in GIS, we first define a non-zero but moderate terrain slope with an interval between $1°$ and $5°$ as the land must not be flat but also only have a gentle slope to satisfy the technicalities required for producing a functional qanat. Given a nearly flat tunnel to ensure adequate water flow while avoiding sediments and erosion, a minimum surface slope is essential for the tunnel to connect with the surface. At the same time, an excessive slope would render it technically unfeasible to excavate a mother well deep enough to access the groundwater table.[17]

In addition, an intermediate clay content is needed for qanats as both hard and soft soil can disturb construction and the performance. With the maximum clay content in the soil being around 500 grams per kilo, we consider an intermediate range of $200-300$ grams per kilo as appropriate for digging, as well as groundwater storage and flow. Both low clay content grounds, consisting mainly of hard rocks or sand, and high clay content ones with soft muddy soil impede digging wells and tunnels and preserving a stable water flow.[18]

Figures 6 and 7 show the relevance of the different levels of terrain slope and clay content in explaining the variations in number of qanats. Figure 6 clearly illustrates that an intermediate interval level of clay content is suitable for qanats at grid level. It resembles a normal distribution, but is skewed to the right as

[17]Considering a nearly flat tunnel, basic calculations reveal that a qanat spanning 1 km in an area with a terrain slope of $1.15°$ would require digging a mother well that is 20 m deep, whereas a depth of approximately 80 m is needed for a slope of $4.57°$. With deeper mother wells generally associated with longer qanats, a $1.15°$ surface would for instance also be suitable for a 5 km long qanat with a mother well reaching a depth of 100 m.

[18]Later in Appendix A.8 we assess the sensitivity of our results to reasonably extended intervals of slope and clay content.

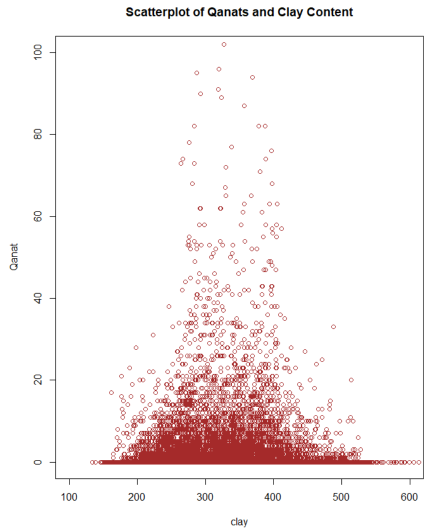


Figure 6: Clay and number of qanats at grid level

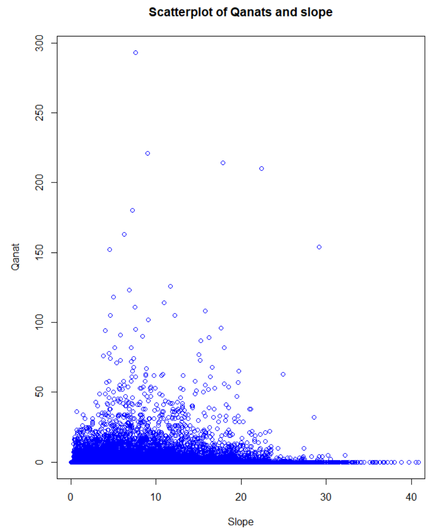


Figure 7: Slope and number of qanats at grid level

a slightly higher clay content does not constitute as much of a problem and is compatible with the technical features of qanats. With analogy, a minimum slope seems to be a requirement for building qanats in Figure 7, whereas it must not be too high for irrigation to be feasible.[19]

An interesting parallel to our IV approach, although different from an engineering perspective, is the work of Duflo and Pande (2007) on large irrigation dams in India. They obtain IV estimates by utilizing variation in dam construction brought about by differences in river gradient across districts within Indian states. They argue that the gradient at which a river flows affects the ease of irrigation dam construction. The slope should be neither flat nor too steep to allow a long reservoir in proportion to the height of a dam, and enable delivery but prevent erosive water velocities. In our case, an (intermediate) clay content is an additional geological factor that facilitates the construction of qanats and adjusts an adequate storage and flow of water to irrigated areas. This second ingredient of our IV conceptually resembles Esposito and Abramson (2021), who use the presence of coal-deposits located on the surface of earth as an exogenous source of variation in coal extraction activities.

The construction of our IV is schematically illustrated in Figure 8. The bottommost layer in the figure shows a hypothetical piece of ground. This layer is then

[19]It will be seen in the first-stage regressions that a combination of slope and clay content explains the variation of qanats significantly and is robust to different specifications and inclusion of controls, guaranteeing the satisfaction of the instrument relevance condition.

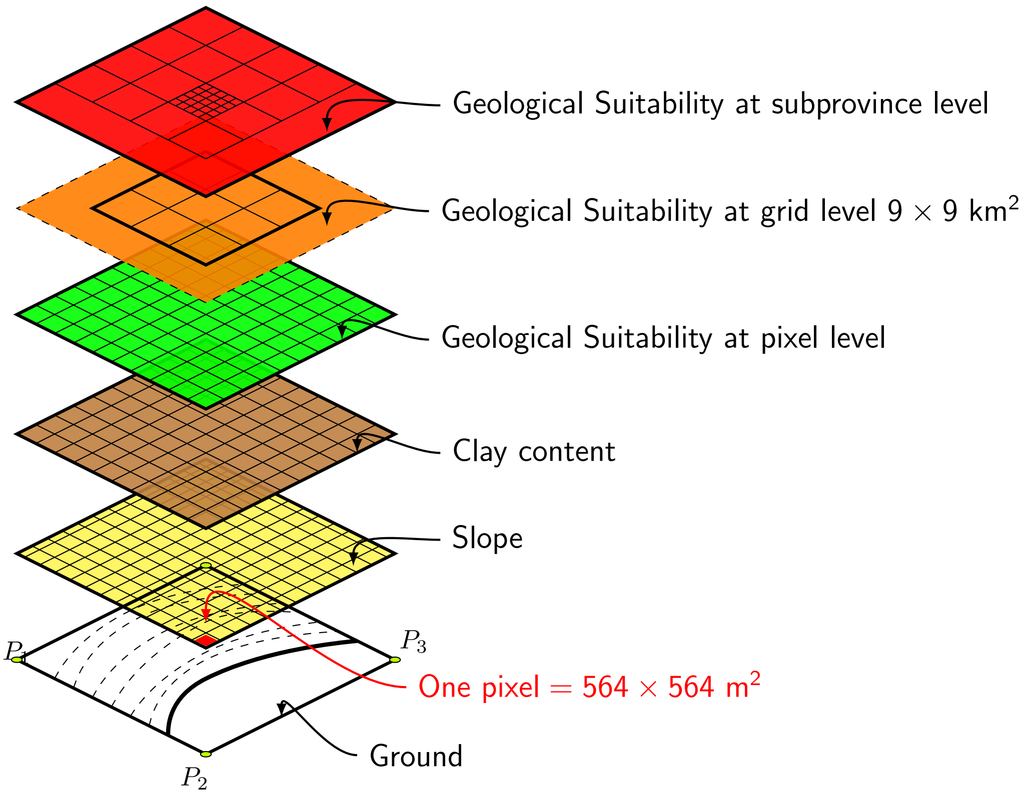


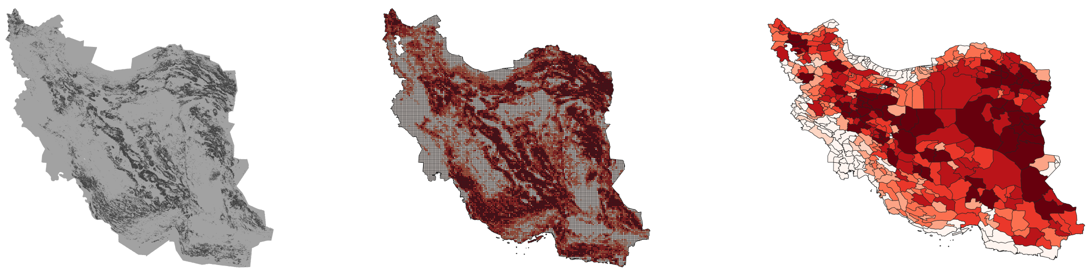
Figure 8: Geological Suitability for Qanats

divided at pixel level which is the finest level we could technically divide the land into (we divided 1.6 million km^2 area of land in Iran into pixel of 564×564 m^2). We then build a layer of clay content and one of slope, each of which can explain the variation of qanats to some extent. We define a pixel of land as geologically suitable for qanats and give it a value 1 if it has a slope of at least 1°, but not greater than 5°, and at the same time a clay content between $200 - 300$gr; otherwise, the value of the pixel is equal to 0. As our standard level of geographical analysis is at the grid level compatible with other geo-data, we aggregate the information to grid level by calculating the sum of pixels with adequate slope and clay content in each grid to produce a continuous variable that measures the proportion of land in the grid that is considered suitable for qanats. With our dependent variable being at the sub-province level, we aggregate further by taking the mean value of grid suitability in each sub-province, which is also equivalent to calculating the proportion of pixels with a value equal to 1.

The first-stage of our IV estimate is shown in equation 2:

$$Q_i = \alpha_1 + \beta_1.G_i + \delta X_i + \upsilon_i, \tag{2}$$

where Q_i is the number of qanats at the sub-province level and G_i is geological suitability. As our aim is to estimate the qanats variable from the OLS regressions, we also standardize the IV per 1000 population. Doing so also accounts for demand and social feasibility of the irrigation technology by giving a higher weight to less densely populated dry or barren areas. Qanats provide a steady flow of water at a low rate and thus play a vital role in supply of local water needs for dispersed rural communities with low volatility of water demand throughout the year (Motiee et al., 2006). Therefore, demand for qanats is greater, and coordination and scale management are more feasible in sparsely populated areas.[20] The major water resource developments in urban areas of Iran involve large systems of pumped wells, whereas isolated and very arid areas continue to depend on qanat systems for the supply of local water needs (Beaumont, 1971).[21] Furthermore, the IV also suggests that at any given level of population, qanats would only be built and prompt cooperation in areas that meet the geological requirements.



IV at Pixel Level　　IV at Grid Level　　Qanats at Sub-province Level

Figure 9: Geological Suitability for Qanats

For a visual verification of the relevance of our IV to the endogenous variables, Figure 9 illustrates whether the locations most suitable for qanats are also areas where qanats have actually been historically constructed. Marking every pixel on the map that meets the required slope and clay features as defined in black, the first panel simulates the most appropriate regions for constructing qanats. The second panel depicts the proportion of suitable pixels in each grid, where light grey represents unsuitable areas and the degree of suitability increases from lighter to darker shades. The third panel of the figure instead shows a heat map of the actual intensity of qanats in each sub-province, again with darker colours indicating a higher density of qanats per population.

[20] Allen et al. (2023) measures the severity of the collective action problem in coordinating and jointly managing canal irrigation by counting the number of settlements in a grid.

[21] Interestingly, Akpoti et al. (2022) finds that population density causes a decrease in suitability for small-scale irrigation between 50 and 250 persons per km^2.

6.2 Instrumental Variable Baseline Results

We begin with the first-stage results illustrated in Table 3. The coefficient of *geological suitability* is positive and statistically significant at 1% level with an F-test mostly above the critical level, guaranteeing the relevance and satisfactory correlation of the instrumental variable to qanats. In Tables A.6.1 and A.6.2 of the Appendix, we show placebos on the first stage so to assure that the selected geological composition did not attract population or explain suitability for major staple crops produced in Iran, using data from Mayshar et al. (2022). Our IV satisfies the test as we always find suitability for qanats to be negatively related to crops and population measures of all periods, with statistical significance in the latter case. It is worth noting that the production of all 9 crops are positively associated with proximity to trade routes and climate stability.

	Dependent variable: Agricultural cooperatives							
								Member share
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A - First-stage								
Geol. suit.	267.1***	217.6***	211.6***	255.1***	254.2***	206.7***	228.2***	228.2***
	(79.9)	(68.8)	(66.7)	(73.0)	(73.2)	(44.5)	(69.0)	(69.0)
Panel B - 2SLS								
Qanats	0.104***	0.143***	0.172***	0.173***	0.172***	0.164***	0.194***	2.554**
	(0.029)	(0.040)	(0.052)	(0.052)	(0.051)	(0.045)	(0.059)	(1.006)
Center prov.			-0.035	-0.037	-0.038	-0.118	-0.028	-0.692
			(0.079)	(0.080)	(0.080)	(0.075)	(0.078)	(1.184)
Arch. sites			0.019	0.018	0.017	0.005	0.014	0.157
			(0.015)	(0.015)	(0.015)	(0.012)	(0.016)	(0.253)
Land suit.				0.123	0.101	0.068	0.010	4.683
				(0.228)	(0.243)	(0.235)	(0.246)	(4.163)
Dist. trade					-0.000	0.000	-0.000	-0.005
					(0.000)	(0.000)	(0.000)	(0.004)
Clim. instab.							0.009	0.837
							(0.693)	(8.546)
constant	0.243***	0.051	0.643	0.608	0.537	-0.000	0.390	6.512
	(0.035)	(0.361)	(0.460)	(0.479)	(0.560)	(0.026)	(0.704)	(9.819)
Geog. Controls	-	X	X	X	X	X	X	X
Census Controls	-	-	X	X	X	X	X	X
Observations	412	412	412	411	411	411	397	392
Province FE						X		
F-test (first-stage)	11.71	9.53	9.37	11.29	11.11	19.97	10.01	9.94

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Dependent variable, qanats, and geol. suit. expressed per 1,000 population. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Qanats and the Number of Agricultural Cooperatives: IV

The rest of Table 3 replicates Table 2 and shows that the IV regressions confirm the OLS results. In all specifications, the coefficient of interest on the estimate of qanats is statistically significant and the sign is positive, confirming our original findings. One can notice that the magnitude of our coefficients is larger than those in the OLS estimations. Our conjecture is that the downward bias is linked to the role of cooperation in maintaining and preserving the irrigation system. Qanats that have deteriorated and eventually disappeared over time in regions with lower levels of cooperation culture are likely underrepresented in the data, which flattens the slope of the regression line and leads to an underestimated coefficient. Our results remain intact when controlling for province fixed effects, under our full specification, and for the share of cooperative members over population as dependent variable.

	Dependent variable: Cooperatives			
	Ind. (OLS) (1)	Ind. (IV) (2)	Total (OLS) (3)	Total (IV) (4)
Qanats	0.018***	0.062***	0.095***	0.707***
	(0.003)	(0.022)	(0.036)	(0.229)
Center prov.	-0.031	0.019	-0.638***	-0.103
	(0.042)	(0.047)	(0.198)	(0.267)
Arch. sites	0.006	0.015*	-0.061	0.027
	(0.008)	(0.009)	(0.043)	(0.055)
Land suit.	-0.102	-0.078	-0.213	0.158
	(0.120)	(0.124)	(0.735)	(0.783)
Dist. trade	-0.000	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.001)	(0.001)
Clim. instab.	0.797**	0.706**	0.877	-0.802
	(0.316)	(0.337)	(1.200)	(2.021)
constant	-0.261	-0.047	4.051*	6.660**
	(0.276)	(0.305)	(2.166)	(3.007)
Geog. Controls	X	X	X	X
Census Controls	X	X	X	X
Observations	400	400	386	386

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Dependent variable and qanats expressed per 1,000 population. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Robustness – Industrial and Total Number of Cooperatives

Next, we assess the impact of irrigation on the creation of other cooperative companies to verify if the behaviour of the coefficients are similar to the case of agricultural cooperatives. To this end, we estimate the same specifications as in Tables 2 and 3 with data for cooperative companies at the industrial sector and also the sum for all sectors. The coefficients behave in a similar manner and the qualitative findings remain the same. Table 4 illustrates the full baseline specification OLS and IV estimates for industrial cooperatives in columns (1)-(2) and for all cooperative types in columns (3)-(4). We observe also more non-agricultural cooperatives today in locations where qanats were historically built, addressing the concern that agricultural cooperatives may have been formed with the purpose of building qanats. Instead, a higher number of industrial and other types of cooperatives reflects a greater level of social capital in locations where a culture of cooperation developed due to the presence of qanats.

In Table A.7.1 of the Appendix, we replace our archaeological-based historic population measure with the number of pre-historic archaeological sites and settlements, as well as contemporary population density, as controls in our favourite specification under both OLS and IV approach. All our findings are confirmed, with pre-historic sites and population density today showing a negative and significant relationship with the pervasiveness of cooperatives in the OLS regressions, just as the original control variable. To test the sensitivity of our IV regarding the technicalities of qanats and the measurements of slope and clay content chosen for our analysis, we relax the upper limit of the original intervals used and extend them to a slope of up to 7° and a clay content of now up to 350 grams per kilo. In Table A.8.1 of the Appendix, we perform the test using our full specification for agricultural, industrial, and total cooperatives in columns (1)-(3), respectively. As it can easily be observed, our variable of interest, Qanats, continues to always have a positive and significant impact, at least at 5% level, on all forms of cooperative activities.

7 Persistence

7.1 Trade and Climate

Since the existence of qanats and their impact on the emergence and adoption of the cooperation culture is a historical question, it is essential to examine various historical episodes to understand alternative or related explanations for cultural variation and persistence across Iran. Recall from the previous sections that we do not observe more cooperatives near ancient trade routes, ruling out a direct role of market access and trade opportunities in determining our outcome. We now shed light on whether trade instead contributed to the persistence of cooperation that stems from qanats by investigating the interaction between distance to trade routes and the presence of qanats. Similarly, knowing that intergenerational stability of the environment plays a role in the persistence of cultures, we test whether it also contributed to the persistence of the qanat cooperation culture. Our main specification will hereafter include the two interaction terms "$Dist.trade \times Qanat$" and "$Clim.instab. \times Qanat$".

	Dependent variable: Cooperatives				
	Agr.	Agr.	Agr.	Ind.	Total
	(1)	(2)	(3)	(4)	(5)
Qanats	0.285***	0.246***	1.046**	0.270**	1.773***
	(0.085)	(0.076)	(0.461)	(0.137)	(0.618)
Center prov.	-0.138*	-0.197***	-0.089	0.003	-0.353
	(0.074)	(0.063)	(0.101)	(0.043)	(0.222)
Arch. sites	-0.006	-0.004	0.006	0.012	-0.025
	(0.012)	(0.011)	(0.020)	(0.008)	(0.048)
Land suit.	0.233	-0.004	0.355	0.007	0.509
	(0.256)	(0.222)	(0.321)	(0.136)	(0.794)
Dist. trade	0.001**	0.001***	0.002*	0.000	0.004***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Dist. trade × Qanat	-0.001***	-0.001***	-0.002**	-0.001*	-0.004***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Clim. instab.			5.045**	1.929**	8.005**
			(2.406)	(0.802)	(3.206)
Clim. instab.× Qanat			-2.076**	-0.501	-3.423**
			(0.980)	(0.307)	(1.581)
constant	0.501	-0.000	-2.604*	-0.784	0.758
	(0.564)	(0.022)	(1.413)	(0.502)	(2.951)
Geog. Controls	X	X	X	X	X
Census Controls	X	X	X	X	X
Observations	411	411	397	400	386
Province FE		X			

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Dependent variable and qanats expressed per 1,000 population. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Interaction of Qanats with Trade and Climatic Instability: IV

The negative coefficient of the interaction term between qanats and distance in the first column of Table 5 suggests that cooperation culture in areas abundant with qanats tends to persist *close* to trade routes. Considering the hypothesis that qanats may have spread via trade routes, this implies that the cooperation culture flourished and persisted only in geographies along the routes where qanats were needed and feasible. The interaction term highlights how the importance of qanats for maintaining trade hubs and caravanserais in arid regions reinforced the cooperation culture over time. The positive coefficient of distance suggests that sub-provinces close to trade routes, which do not host a large number of qanats, do not exhibit a higher concentration of agricultural cooperatives today. Trade therefore does not cause but may contribute to the persistence of the qanat-induced cooperation culture by inducing the preservation of qanats for the provision of water and services to merchants.[22] We can observe in column (2) that the aforementioned relation also holds within sub-provinces.

[22]One can also relate the role of trade on persistence of cooperation to how it contributed to eliminate attitudes associated with hatred and conflict over time (Voigtlaender and Voth, 2012).

Observing trade routes allows us to explore a potential channel through which trade interacted with qanats to contribute to cultural persistence over time. Nonetheless, it remains a challenging task to argue the persistence of the cooperation culture created by socioeconomic aspects of qanats, in the form of social capital and cooperative enterprises today.[23] In order to address this concern, we resort to information on climate instability across generations between 500 and 1900 A.D. from Giuliano and Nunn (2021) to identify the role of regional variation in the persistence of culture. They show that cultural traits persist when the environment is more similar across generations, whereas they are not maintained in populations living under unstable climatic conditions.

In columns (3)-(5) of Table 5 we have added the measure of climate instability and its interaction with qanats to our regressions for agricultural, industrial, and all cooperatives, respectively. The results support the trade findings and confirm the notion of cultural persistence presented in the thesis of Giuliano and Nunn (2021). We observe the persistence of the cooperation culture in environmentally stable regions by finding a negative interaction effect between qanats and the climatic variability measure on cooperatives today, reinforcing the validity of our key results in these areas: placing the cooperation nurtured by qanats into the Giuliano and Nunn (2021) framework, such institutions are more likely to evolve to culture and become entrenched in the society in form of social capital in areas that were not exposed to severe climate shocks across generations. More variability could eventually lead to the inactivity of qanats and disrupt the intergenerational transmission of culture. This would weaken the persistence mechanism and consequently materialize into less cooperation today. In other words, although the existence of qanats in sub-provinces that fall under more climatically unstable regions may have led to cooperation at the time for subsistence, they do not exhibit a higher number of cooperatives today.

7.2 Impact on Social Structure Today

To conclude the analysis, we test our hypothesis by using alternative available proxies for social capital to understand whether the cooperation culture transmitted to today's society has had a more concrete impact on the social structure, for example in terms of religion, general morality, or trust.

[23] See Spolaore and Wacziarg (2013); Nunn (2014); Voth (2021) for a detailed discussion on the persistence of the impact of historical events and how they interact with geographical factors to determine present-day outcomes.

	Dependent variable: Islamic credit inst.						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Qanats	0.002***	0.001***	0.001***	0.001***	0.001***	0.001**	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Center prov.			-0.004*	-0.004*	-0.004	-0.005**	-0.003
			(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Arch. sites			-0.000	-0.000	-0.000	0.000	-0.000
			(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
Land suit.				-0.001	0.001	-0.007	-0.001
				(0.008)	(0.008)	(0.010)	(0.008)
Dist. trade					0.000	-0.000	0.000
					(0.000)	(0.000)	(0.000)
Clim. instab.							0.032
							(0.022)
constant	0.010***	0.026**	0.009	0.001	0.007	0.000	-0.006
	(0.001)	(0.013)	(0.018)	(0.019)	(0.019)	(0.001)	(0.021)
Geog. Controls	-	X	X	X	X	X	X
Census Controls	-	-	X	X	X	X	X
Observations	428	428	428	427	427	427	413
R-squared	0.06	0.09	0.12	0.13	0.13	0.09	0.15
Province FE						X	

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Dependent variable and qanats expressed per 1,000 population. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Qanats and Credit Institutions

As a first test, we have obtained information on the presence of particular moral-based Islamic microfinance institutions called *Qard al-Hasan*. In such Islamic banks, loans are extended without a collateral on goodwill basis mainly to the poor and the needy, with the borrower being considered god, not the person receiving the money. Conceptually, we link the idea of a more cooperative society with more willingness for the functioning of such welfare systems. Using the pervasiveness of these institutions in each sub-province as an alternative measure of social capital today, Table 6 replicates our baseline OLS regressions in Table 2 and shows that the link between qanats and the social capital structure today solidly stands. The results are also in line with the thesis in Henrich (2020) that shocks cause more investment in communities, more cooperative norms, and more religious commitments.

We have also gathered data on the more commonly known measure of trust. The 7th round of the WVS (2017 − 2021) enables us to geo-locate 133 towns across Iran where the survey was conducted, allowing us to exploit the granular nature of our qanat data. In our context, we are interested in the measure that most closely captures trust within a local community, to represent the cooperation culture fostered by qanats. We hence use the question regarding the extent to which participants trust their neighbours. We create a dummy variable that is equal to one if respondents somewhat or completely trust their neighbour, and zero if they do not trust their neighbours much or at all. We assess whether a higher number of qanats in the survey location leads the members of a community to feel more trust towards their neighbours.

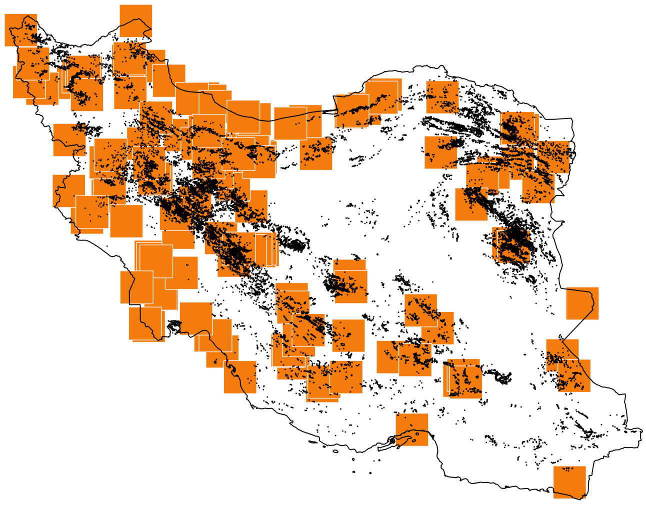


Figure 10: Qanats and Trust in Neighbours

This final exercise also allows us to exploit the disaggregated nature of the data for our main dependent variable to test whether the relation also exists within narrow grids. We therefore revisit our original data on qanats, and count the raw number of qanats within equal 50 km buffers of locations where the survey was conducted. The map in Figure 10 depicts again qanats in Iran together with the buffered areas around the 133 survey locations. It is worth noting that this level of analysis differs from our baseline specification and allows us to include individual-level controls such as age, gender, settlement size of the survey location, and account for ethnic group and town fixed effects in place of sub-province level census and geographical controls. We do however calculate suitability of land for agriculture in each buffered area as another key control variable.

The results are presented in Table 7 and clearly exhibit a positive relationship between the number of qanats and trust in neighbours across different specifications. Column (1) shows the basic OLS regressions, whereas column (2) clusters standard errors at ethnic group level, and column (3) further add ethnic group fixed effects to exploit variation within ethnic groups. The same procedure is repeated at town level in columns (4)-(5). Overall, respondents in areas endowed

	Dependent variable: Trust in neighbours				
	(1)	(2)	(3)	(4)	(5)
Nr. Qanats	0.00004**	0.00004***	0.00004***	0.00004**	0.00004***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age	0.00519***	0.00519***	0.00532***	0.00519***	0.00563***
	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
Gender	-0.06597***	-0.06597***	-0.06012***	-0.06597***	-0.06912***
	(0.021)	(0.018)	(0.015)	(0.019)	(0.020)
Settlement size	-0.02636***	-0.02636***	-0.02669***	-0.02636***	-0.02900***
	(0.007)	(0.008)	(0.008)	(0.005)	(0.001)
Land suit.	0.09708	0.09708	0.24064	0.09708	0.35701***
	(0.098)	(0.113)	(0.177)	(0.125)	(0.007)
constant	0.74289***	0.74289***	0.71311***	0.74289***	0.70785***
	(0.051)	(0.042)	(0.036)	(0.050)	(0.049)
Observations	1493	1493	1493	1493	1493
R-squared	0.05	0.05	0.05	0.05	0.06
Ethnic cluster		X	X		
Ethnic FE			X		
Town cluster				X	X
Town FE					X

Standard errors in parentheses. Questionnaire: How much do you trust people from your neighbourhood? 0: do not trust very much; do not trust at all; 1: trust completely; trust somewhat. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Impact of Qanats on Trust in Society

with a greater number of qanats tend to trust their neighbours more. Older individuals are also associated with a higher level of trust, whereas the opposite is observed among females and in larger communities.

8 Concluding Discussion

We study the link between irrigation and collective norms at sub-province level in Iran. The main goal of this study was to explore the relationship between a specific pre-modern irrigation technology, the qanat, and cooperation. We have acquired detailed data from the Agricultural Ministry of Iran on the geographic coordinates of qanats throughout the country. We build and instrument using information about the technical features of qanats and the corresponding geographic variables and GIS tools to mitigate possible endogeneity concerns regarding this technology. Our instrumental variable consists of identifying lands adequate for the construction and use of qanats with a gentle slope and an intermediate clay content. A within-country analysis allows us to rule out political economy factors and differences in institutions that can play a key role in determining the impact of historical irrigation practices on social capital across countries and regions in the world.

We find a positive relationship between the historical presence of qanats and the formation of cooperative companies in Iran today. The coefficients are stable across different specifications controlling for various demographic and geographic covariates and stand up well to a battery of robustness checks. Since qanats are mostly used for agricultural purposes, the baseline analysis is for agricultural cooperatives companies. However, to further exploit the effect and the evolution of the culture of cooperation, we also use industrial and all cooperative companies as the dependent variable to support our results. In all our estimates we control for land suitability, which is key to rule out qanats being built around or leading to fertile grounds that can affect contemporary outcomes. In addition, we show that qanat locations do not seem to be a driver of population density, unlike literature on path dependence that show the impact of historical events on population and economic activity today.

The necessity for cooperation concerning qanats extends over time due to their continuous need for maintenance, contributing to the persistence of the culture. While qanats may have been constructed hundreds of years ago, the users need to cooperate together as long as they are operational and the users are extracting water. A key contribution of the paper is to highlight how qanat sites interact with trade and climate variability in determining the persistence of the cooperation culture. We find that the qanat-induced culture is more likely to persist across generations along ancient trade routes and under more stable climatic conditions. Interestingly and in line with our hypothesis, proximity to trade routes and more cross-generational environmental stability themselves do not display a higher (if not lower) level of cooperative activities today.

We strengthen our results by looking at alternative contemporary measures of social capital, namely the pervasiveness of Islamic charity-like microfinance institutions across sub-provinces, and trust in neighbours in 133 locations across Iran where the WVS questionnaires were distributed. The positive relationship between qanats and the cooperation culture today firmly persists and suggests how institutions required to run such traditional irrigation system could have survived inherently in the society in the form of culture. We believe the existence of qanats could therefore be an explanation for the persistence of cooperation culture and the prevalence of social capital today. This study paves the way for future research that can further exploit the level of granularity of the data. Some avenues include examining whether qanats can influence dealing with climate shocks, reduce drought-related conflicts, or promote democratic movements by influencing a society's coordination capacity.

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A Appendix

A.1 Geographical Attributes of Iran

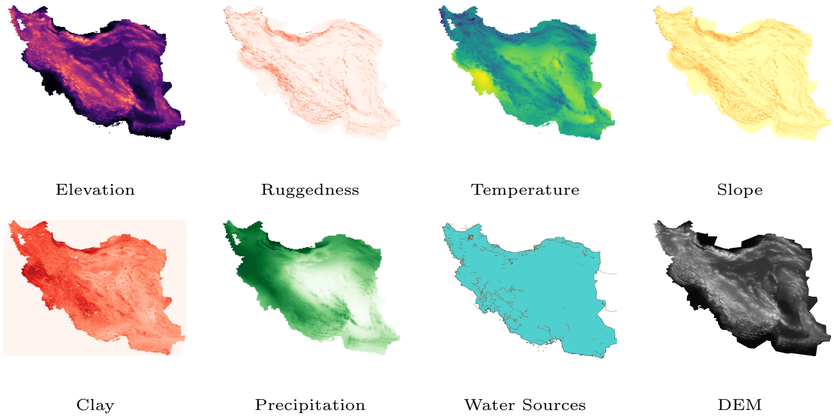

Figure A.1.1: Geographic Data

A.2 Data Description

Agr. coop.: The number of agricultural cooperatives per 1,000 population at the sub-province level.

Agr. coop. member: The share of the sub-province population who are members of agricultural cooperatives: number of members per 1,000 population of the sub-province.

Annual precip.: Annual precipitation in 1km × 1km grids aggregated by mean at sub-province level.

Arch. sites: The number of archaeological sites prior to 476 A.D. (anchientlocations.net) obtained at grid level from Mayshar et al. (2022) aggregated for each sub-province.

Barley, Buckwheat, Foxtail, Maize, Oat, Rye, Sorghum, Wheat, and Potato: Historically most relevant domesticated cereals, roots and tubers in Iran. The value represent median of agro-climatically yield (calories/ha) for low input level rain-fed crop obtained at grid level from Mayshar et al. (2022) aggregated to sub-province level.

Center prov.: A dummy variable equals to 1 for the capital of a province.

Clay content: The average clay content across grids (250m × 250m) within a sub-province.

Climate instab.: Mapped the value of intergenerational climate instability (500-1900 A.D.) from 5° × 5° grid cells to sub-provinces when all or the majority of a sub-province is contained in a cell.

Dist. trade: Distance of the centroid of a sub-province to the nearest point on 600 A.D. trade route (km).

Elevation: The average elevation across pixels within a sub-province.

Empl. rate: Ratio of employed individuals to population aged 15+ at sub-province level in 2016 (Statistical Center of Iran).

Gender: A binary variable set to 1 if the respondent is male and 2 if female. (World Value Survey, W7)

Ind. coop.: The number of industrial cooperatives per 1,000 population at the sub-province level.

Islamic credit inst.: The number of Qard al-Hasan institutions at each sub-province.

Land suit.: Land suitability in 0.5° × 0.5° grids aggregated by mean at sub-province level.

Lit. rate: Number of literate individuals divided by population at sub-province level in 2016 (Statistical Center of Iran).

Max temp.: Max temperature in 1km × 1km grids aggregated by mean at sub-province level.

New sub-province: A dummy variable equals to 1 for newly recognized sub-provinces after the recent reform in administrative divisions of Iran.

Nr. qanats: Number of qanats within a 50 km buffer around each survey location. (based on authors' own calculations)

Prehist. arch. ruins: The number of post-Neolithic sites (Whitehouse & Whitehouse, 1975) obtained at grid level from Mayshar et al. (2022) aggregated for each sub-province.

Prehist. settlements: The number of post-Neolithic settlements (Whitehouse & Whitehouse, 1975) obtained at grid level from Mayshar et al. (2022) aggregated for each sub-province.

Pop. dens.: Population in 2016 divided by area of the sub-province (Statistical Center of Iran based on authors' own calculations).

Qanats: Number of qanats at the sub-province level per 1,000 population.

Ruggedness: The average ruggedness across pixels within a sub-province.

Settlement size: indicates the size of the settlement where the respondent is located, classified into five groups: 1. Under 5,000, 2. 5,000-20,000, 3. 20,000-100,000, 4. 100,000-500,000, 5. 500,000 and above. (World Value Survey, W7)

Slope: The average slope across pixels within a sub-province.

Total coop.: The number of all cooperatives per 1,000 population at the sub-province level.

Trust in neighbours: Dummy variable set to 1 if the answer to the following question is 1 or 2, and 0 otherwise: " I'd like to ask you how much you trust people from various groups. Could you tell me for each whether you trust people from this group completely, somewhat, not very much or not at all? Your neighborhood: 1. Trust completely, 2. Trust somewhat, 3. Do not trust very much, 4. Do not trust at all."

Water sources: Dummy variable equal to 1 in presence of waterways including linear water features such as rivers, canals, and streams, as well as water areas such as lakes, reservoirs, and docks. Related features include barriers to navigation such as locks, weirs, dams, and rapids.

A.3 Robustness Checks

A.3.1 Raw Number of Qanats in each Sub-province

	Dependent variable: Agricultural cooperatives							
	Number							Population share
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lnQanats	0.131***	0.172***	0.158***	0.159***	0.156***	0.163***	0.196***	2.367***
	(0.036)	(0.039)	(0.040)	(0.040)	(0.040)	(0.046)	(0.041)	(0.697)
Center prov.			-0.177***	-0.178***	-0.181***	-0.235***	-0.183***	-2.801***
			(0.056)	(0.056)	(0.057)	(0.054)	(0.055)	(0.741)
Arch. sites			-0.018	-0.018	-0.020*	-0.007	-0.019	-0.289
			(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.189)
Land suit.				0.098	0.030	-0.070	-0.043	3.800
				(0.202)	(0.222)	(0.217)	(0.227)	(3.877)
Dist. trade					-0.000	0.000	-0.000	-0.004
					(0.000)	(0.000)	(0.000)	(0.003)
Clim. instab.							0.255	4.449
							(0.488)	(5.439)
constant	0.312***	-0.099	-0.025	-0.085	-0.293	0.000	-0.423	-4.404
	(0.025)	(0.326)	(0.370)	(0.378)	(0.430)	(0.019)	(0.503)	(6.906)
Geog. Controls	-	X	X	X	X	X	X	X
Census Controls	-	-	X	X	X	X	X	X
Observations	412	412	412	411	411	411	397	392
R-squared	0.04	0.06	0.08	0.08	0.08	0.08	0.11	0.08
Province FE						X		

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Dependent variable is per 1,000 population and the qanat count is expressed in logs. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.3.1: Log of Qanats and the Number of Agricultural Cooperative

A.3.2 Testing the Demographic Controls

	Dependent variable:			
	Literacy rate	Employment rate	Agri. Coop.	Agri. Coop.
	(1)	(2)	(3)	(4)
	(OLS)	(OLS)	(OLS)	(IV)
Qanats	0.002	0.001	0.031***	0.193***
	(0.001)	(0.001)	(0.006)	(0.058)
Lit. rate		0.031**		
		(0.016)		
Empl. rate	0.765***			
	(0.257)			
Center prov.	0.082***	-0.010**	-0.193***	-0.007
	(0.024)	(0.004)	(0.053)	(0.075)
Arch. sites	-0.006	0.001	-0.025**	0.012
	(0.007)	(0.001)	(0.012)	(0.016)
Land suit.	0.076	-0.041***	-0.037	0.092
	(0.063)	(0.013)	(0.220)	(0.238)
Dist. trade	0.000**	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Clim. instab.	0.634***	-0.033	0.509	0.122
	(0.126)	(0.029)	(0.465)	(0.642)
constant	-0.033	0.352***	-0.669	-0.144
	(0.251)	(0.033)	(0.414)	(0.502)
Geog. Controls	X	X	X	X
Observations	413	413	397	397
R-squared	0.14	0.13	0.09	

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. The new sub-province dummy is included. Dependent variable is per 1,000 population and the qanat count is expressed in logs. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.3.2: Testing for Potential Bad Controls

A.4 Qanats and Population

A.4.1 Population Density

	Dependent variable: Population Density						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\hat{Qanats}$	-0.142	-0.275	-0.343	-0.335	-0.345	-0.027	-0.372
	(0.102)	(0.212)	(0.216)	(0.210)	(0.219)	(0.072)	(0.265)
Arch. sites				14.633	12.626	23.260**	11.992
				(9.583)	(8.442)	(10.265)	(7.482)
Land suit.				682.659	598.388	469.479*	618.431*
				(431.214)	(364.691)	(280.676)	(369.447)
Dist. trade					-0.264	0.071	-0.249
					(0.265)	(0.164)	(0.292)
Clim. instab.							2.621
							(275.128)
constant	164.258***	1031.729**	680.252**	569.945*	334.934	0.000	354.911
	(55.876)	(492.145)	(324.361)	(291.479)	(235.950)	(27.687)	(288.362)
Geog. Controls	-	X	X	X	X	X	X
Census Controls	-	-	X	X	X	X	X
Observations	421	421	421	420	420	420	406
R-squared	0.00	0.04	0.08	0.09	0.10	0.09	0.10
Province FE						X	

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Dependent variable is expressed per 1,000 population. $\hat{Qanats}$ is not normalized in this regression as population appears in the dependent variable. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.4.1: Non-result for Population Density

A.4.2 Historical Population

	Dependent variable:		
	Arch. sites (1)	Prehist. arch. sites (2)	Prehist. settlements (3)
Qanats	-0.063***	-0.029***	-0.019***
	(0.016)	(0.010)	(0.007)
Land suit.	0.663	0.648	0.672
	(0.964)	(0.706)	(0.701)
Dist. trade	-0.002***	-0.002***	-0.002***
	(0.001)	(0.001)	(0.001)
Clim. instab.	-6.397***	-1.578**	-2.080***
	(1.235)	(0.739)	(0.717)
constant	-5.170***	-3.220**	-2.733*
	(1.768)	(1.444)	(1.480)
Geog. Controls	X	X	X
Observations	413	409	409
R-squared	0.29	0.21	0.20

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Qanats expressed per 1,000 population. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.4.2: Qanats and Historical Population

A.5 Qanat Map at Sub-province and Grid Level

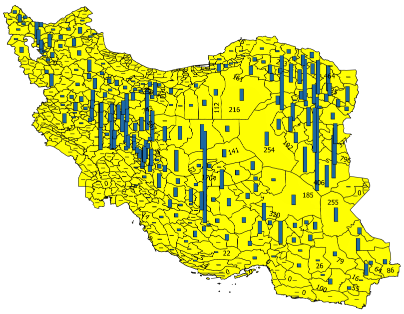

Figure A.5.1: Qanat Count at sub-provinces

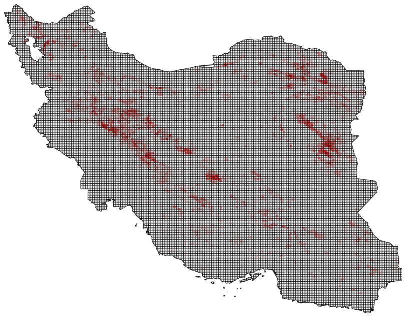

Figure A.5.2: Gridded map of Iran $9km \times 9km$

A.6 First-stage Placebo

A.6.1 Population Settlements

	Dependent variable:		
	Pop. dens.	Prehist. arch. sites	Prehist. settlements
	(1)	(2)	(3)
Geol. suit.	-35686.081*	-29.775***	-16.847**
	(20666.549)	(10.306)	(7.512)
Center prov.	248.129	0.006	0.024
	(185.669)	(0.214)	(0.208)
Arch. sites	10.196	0.425***	0.426***
	(6.967)	(0.055)	(0.055)
Land suit.	509.463*	0.081	0.148
	(308.685)	(0.448)	(0.448)
Dist. trade	-0.294	-0.001***	-0.001*
	(0.308)	(0.000)	(0.000)
Clim. instab.	117.723	1.019*	0.650
	(280.246)	(0.578)	(0.546)
constant	377.892	-1.275	-0.647
	(302.330)	(1.011)	(1.045)
Geog. Controls	X	X	X
Census Controls	X	X	X
Observations	406	409	409
R-squared	0.12	0.54	0.55

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Geol. suit. expressed per 1,000 population. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.6.1: Placebo: Population Settlements

A.6.2 Crop Suitability

	Dependent variable:								
	Barley (1)	Buckwheat (2)	Foxtail (3)	Maize (4)	Oat (5)	Rye (6)	Sorghum (7)	Wheat (8)	Potato (9)
Geol. suit.	-148746.1	-27194.6	-309999.9**	-358428.2**	-91953.3	-60458.1	-127969.9	-142484.6	-22841.1
	(195593.8)	(82314.3)	(131546.9)	(170679.8)	(70203.3)	(94324.6)	(149558.4)	(187572.2)	(43266.1)
Center prov.	191.2	254.6	-437.4	3153.0	-305.8	-363.7	735.3	340.7	273.9
	(2171.3)	(1056.2)	(1709.0)	(2348.9)	(895.8)	(1330.7)	(1859.3)	(2084.4)	(517.1)
Arch. sites	410.7	412.2**	-1233.7***	-1758.0***	231.8	101.9	330.5	397.9	112.3
	(405.3)	(202.9)	(356.1)	(588.1)	(173.2)	(257.7)	(348.1)	(397.1)	(129.1)
Land suit.	2438.6	-2831.8	-1176.9	-11589.2	326.2	4113.9	-592.1	1602.5	-2279.6
	(6893.6)	(2746.7)	(7532.0)	(11324.1)	(2631.7)	(5107.0)	(6563.4)	(6720.1)	(1565.4)
Dist. trade	-34.8***	-18.3***	-32.9***	-11.9**	-16.4***	-22.7***	-26.2***	-32.7***	-6.2***
	(5.2)	(2.4)	(4.0)	(6.0)	(2.0)	(3.1)	(4.3)	(5.0)	(1.2)
Clim. instab.	-91616.7***	-41586.1***	-36212.4***	5071.7	-32322.4***	-43738.7***	-59089.9***	-86221.5***	-17637.3***
	(10404.4)	(4661.9)	(8094.1)	(13932.3)	(4056.0)	(6084.7)	(8704.7)	(10059.5)	(2529.9)
constant	49048.3***	17688.6***	45588.2***	-7386.4	4065.8	15281.2*	53243.9***	44442.2***	7242.6**
	(13127.4)	(6135.8)	(10957.2)	(16921.1)	(5156.4)	(8242.0)	(11570.7)	(12653.8)	(3308.6)
Geog. Controls	X	X	X	X	X	X	X	X	X
Census Controls	X	X	X	X	X	X	X	X	X
Observations	413	413	413	413	413	413	413	413	413
R-squared	0.74	0.68	0.71	0.69	0.76	0.74	0.66	0.74	0.75

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Geol. suit. expressed per 1,000 population. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.6.2: Placebo: Crop Suitability

A.7 Alternative Population Controls

	Dependent variable: Agricultural cooperatives					
	(1) (OLS)	(2) (IV)	(3) (OLS)	(4) (IV)	(5) (OLS)	(6) (IV)
Qanats	0.033***	0.209***	0.031***	0.192***	0.032***	0.192***
	(0.006)	(0.069)	(0.006)	(0.058)	(0.006)	(0.058)
Center prov.	-0.193***	-0.015	-0.213***	-0.030	-0.214***	-0.029
	(0.055)	(0.078)	(0.057)	(0.077)	(0.057)	(0.077)
Pop. dens.	-0.000***	0.000				
	(0.000)	(0.000)				
Prehist. arch. sites			-0.041**	-0.004		
			(0.018)	(0.020)		
Prehist. settlements					-0.030	-0.006
					(0.018)	(0.022)
Land suit.	-0.072	0.024	-0.060	0.070	-0.069	0.072
	(0.227)	(0.248)	(0.253)	(0.268)	(0.254)	(0.268)
Dist. trade	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Clim. instab.	0.411	-0.259	0.418	-0.098	0.421	-0.103
	(0.482)	(0.725)	(0.483)	(0.678)	(0.483)	(0.682)
constant	-0.211	0.418	-0.436	0.318	-0.366	0.315
	(0.515)	(0.744)	(0.534)	(0.747)	(0.531)	(0.737)
Geog. Controls	X	X	X	X	X	X
Census Controls	X	X	X	X	X	X
Observations	392	392	393	393	393	393

Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Dependent variable and qanats expressed per 1,000 population. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.7.1: Alternative Population Controls

A.8 IV Sensitivity Analysis

	Dependent variable: Cooperatives		
	Agr. (1)	Ind. (2)	Total (3)
Qanats	0.189***	0.067***	0.556**
	(0.063)	(0.025)	(0.250)
Center prov.	-0.034	0.026	-0.235
	(0.085)	(0.048)	(0.254)
Arch. sites	0.013	0.017*	0.006
	(0.019)	(0.009)	(0.054)
Land suit.	0.007	-0.074	0.066
	(0.239)	(0.124)	(0.748)
Dist. trade	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.001)
Clim. instab.	0.020	0.694**	-0.387
	(0.681)	(0.347)	(1.825)
constant	0.364	-0.020	6.015**
	(0.741)	(0.323)	(2.885)
Geog. Controls	X	X	X
Census Controls	X	X	X
Observations	397	400	386

IV uses the extended range of suitability measures: 1-7 degrees slope and 200-350g clay content. Conley standard errors with 50 km radius (with a linear decay) in parenthesis. Geographic controls at mean are annual precip., clay content, slope, elevation, ruggedness, max temp., plus a dummy for access to water sources. Census controls are lit. rate, empl. rate, plus the new sub-province dummy. Dependent variable and qanats expressed per 1,000 population. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.8.1: IV Robustness Tests