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Qanats *

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Abstract

Qanats – traditional Persian irrigation systems first built around 1000 B.C. – 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 together with information collected and digitized on cooperative enterprises and find a positive relationship between qanat locations and cooperative activities today. We build an IV using grid-level geological preconditions necessary for the construction and functioning of qanats: gently sloped terrains and intermediate clay content. The cooperation culture persists particularly close to historical trade routes and in areas with stable climatic conditions. The results hold for alternative proxies of social capital, namely the degree to which people trust their neighbours and the pervasiveness of charity-based Islamic microfinance establishments.

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

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

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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. Collective action is 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), which 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, 1993; Guiso et al., 2016).

We study the role of historical qanats within Iran on the origins of cooperation that emerged as an institution in local communities, became a regularity for the continued use of qanats, and persisted as the cooperation culture. We argue that these institutions were born as means of survival. 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 of the fact that we are studying the importance of secular institutions, whereas most studies emphasize religion. 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, proximity to trade routes is not a predictor of social capital today, but contributed to the persistence of the qanat-induced cooperation culture, as did a more stable environment across generations.

We construct unique geo-localized data on the location of all qanats that have been documented in Iran ($40,850$) and digitize provincial data on cooperatives organizations for each Iranian sub-province. Data on the precise location of qanats allows us to use actual data on historical irrigation systems, as opposed to climatic data, to study the emergence and persistence of the cooperation culture in irrigation communities in the form of local cooperative activities today. 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 minimum slope for every topology to make it functional, the clay content of soil is essential to assure feasibility of digging wells, as well as groundwater storage and flow. Using this information helps to identify the effect of qanat-induced cooperation not only through the demand for this technology, but also conditions that render it feasible to exist. 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.

The history of qanats in Iran goes as far back as $3,000$ years ago, when this technology was invented in the Central Iranian Plateau to bring mountain ground water 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).

The qanat is a complex pre-modern irrigation technology that requires maximum degree of interdependence and cooperation as its engineering, building, and maintenance was beyond the ability of individuals (Spooner, 1974). Extracting water also demanded different levels of investment, technology and organization. Water from the qanats was shared among a group of people and required rules for cleaning, repairing and sharing, giving rise to a community of water users (Charbonnier, 2018). Each qanat had many owners and the water was divided into shares, with the shareholders being granted an interval to bring qanat water to their land.[2] The lack of outside opportunities like access to urban or market connections is another factor that stimulates cooperation in qanat-dependent arid regions. With the need for irrigation vital in different areas, the geographic features of water resources and the characteristics of the adopted technology contributed to the development of cooperative norms and inclusive institutions.

Yet, a key distinction of the qanat irrigation system that induces stronger norms of cooperation is the relatively small scale of the system making it more of a common pool resource institution (Weissing and Ostrom, 1991; Bardhan, 2000; Dayton-Johnson and Bardhan, 2002). The same concept applies 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). This is different from capital-intensive large irrigation project for which economies of scale and the centralization of power were crucial (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 collapse of the cradle of civilization in Mesopotamia as a result of the inability of the state to maintain irrigation systems. Despite the agricultural productivity of the region, particularly *Sawad* in Southern Iraq which was the foundation of the Arab empire, its geography made it dependent on irrigation and state support was vital for producing the necessary long-distance canals. The Persian empire instead relied on small-scale qanats mostly 5–10 km in length, 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 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).

[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]Qanat users had an irrigation right of 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).

Turning to the outcome variable, 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." They are generally considered social capital-based organizations, with trust and cooperation as their basic pillars.[3] 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). The stock of social capital available at the community level favours the creation and development of cooperatives by accumulating different assets that increase cooperative behaviour for a mutual benefit (Uphoff, 2000; Arando et al., 2012; Bauer et al., 2012). Specifically, three key factors that link cooperatives to social capital are trust, associative density, and civic participation (Putnam et al., 1994).[4] It is easier to build cooperatives 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 conjecture. Finally, we test our argument directly on the level of trust today by using information from the World Value Survey (WVS) wave 7, with the relevant question being whether the participants trust their neighbours. The survey was conducted across 133 locations in Iran. After geo-locating the towns in which the questionnaire was distributed, we count the number of qanats within a 50km buffer and find that a higher number of qanats explicitly result in trust within a neighbourhood community. 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.

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

Our conjecture builds on the more general theoretical premise that irrigation shapes stronger norms of cooperation (Weissing and Ostrom, 1991). Cooperation is defined as a group of individuals interacting to achieve a common goal, whose support for community norms and governance gives rise to social capital (Bowles and Gintis, 2002). Social values and norms breed

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

[4] See e.g. Jones and Kalmi (2009) for evidence on trust.

mutual cooperation by enhancing trust among individuals (Ostrom and Ahn, 2003). Social capital is thus generally linked to trust, but its historical origins remain largely unexplored (Tabellini, 2010). Since the pioneer works of Coleman (1990) and Putnam (1993), the concept of social capital has been associated with successful collective action to provide and maintain physical capital, with a prime example being irrigation systems (Ostrom, 1994). Requiring indispensable collective efforts and governance to optimally coordinate scarce water supply and monitor participants' obligations, irrigation nurtures interdependent communities. The emerging norms naturally evolve over time to guarantee survival, and become a part of the culture of traditional irrigation communities (Boyd and Richerson, 1988). Past experience of cooperation builds the necessary organizational skills and trust that determine future collective effort (Ostrom, 1990). Traditional irrigation communities therefore formed the basis of local cooperation, and contributed to social capital in future generations.

Although 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.

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.[5] 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 the irrigation dependence and irrigation potential proxies calculated at global level, most of Iran is not suitable for agriculture, with a few feasible spots obtaining a class 5 irrigation impact. This gives a score of full irrigation potential ($\frac{\text{class 5}}{\text{land suitable for agriculture}} = 1$) with the rest of Iran neglected from the analysis. This may lead to missing information on variations within Iran, as in some areas qanats are the only means of subsistence.[6] 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 data on qanats and cooperatives makes it possible to study the link between the cooperation required by the complex traditional irrigation technology and social capital today at the local level. Iran is a particularly suitable case for such analysis as cooperatives are a recent phenomenon relative to the ancient history of qanats. The land reform of the 1960s led to the redistribution of land in favor of peasants through a mechanism of joint ownership through cooperatives, which are considered the most important institutional arrangement of the reform (Lambton, 1969). We argue that the geographical and technical features of qanats nurtured the culture of cooperation prior to the liberalization. Once possible after the 1960s, these were the areas that saw the foundation of more cooperative enterprises. Our dataset allows us to make this distinction because after this juncture qanats were substituted with modern technologies by the construction of large water dams and deep wells with electric and fuel-powered pumps (Allan, 2005). 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,

[5] 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.

[6] 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.

more than 14,000 qanats dried out due to falling water tables related to extractions of 500,000 pumped wells around the country (Delavari-Edalat and Abdi, 2017).

Our study contributes to a long list of literature surveyed in Nunn (2014) 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 are no longer in place.[7] The dynamic mechanism differs from setups with a contemporaneous relationship between institutions and culture such as Henrich et al. (2001), where cooperation in a society is contingent upon the cooperative nature of its current mode of production. Qanats are not a static shock. Their preservation is a continuous dynamic phenomenon across generations. And they have been built throughout history at different points of time from ancient periods to the 1960s. Importantly, the qanat system is a sustainable form of irrigation unlike other modern mechanical methods.

3 Technical Features of Qanats

The qanat irrigation systems are almost entirely found in zones with total precipitation between 100 and 300mm, 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 in Iran are individually of a small scale (Manuel et al., 2018).[8]

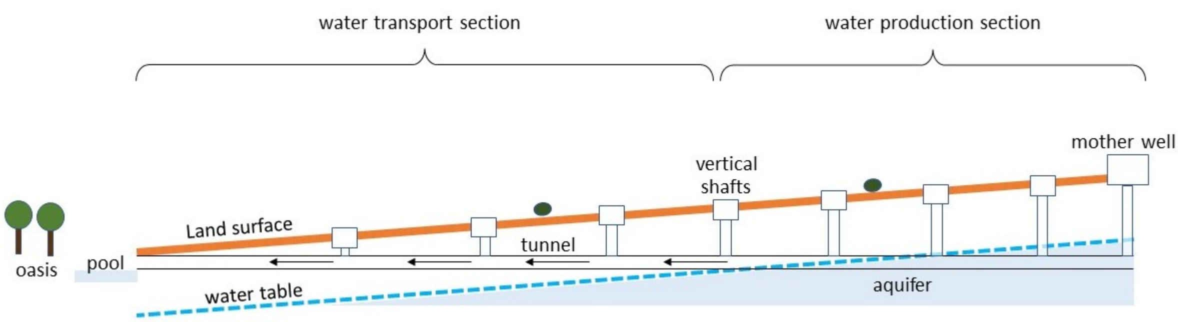


Figure 1: Profile of a typical Qanat

A qanat is an underground gallery that bring water from an aquifer to low elevation dry lands via gravity without requiring energy and with a balanced natural inflow and outflow. It

[7] See also (Karaja and Rubin, 2022) on an experiment to study how historically institutionalized cultural norms could be transmitted intergenerationally.

[8] A study of 266 qanats in the Varamin Plain in Iran showed lengths that varied between 2–5km in length, with each village having access to only one qanat (Beaumont, 1968).

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. 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 consist 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. Additional shafts are dug at closely spaced intervals of 20–200m 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, maintenance and cleaning purposes (Cressey, 1958).

A minimum terrain slope is necessary for qanats to be technically feasible. The tunnel must therefore be gently sloped, nearly horizontal and flatter than the terrain, to eventually intersect with the surface. 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). Among geological features, 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), which is particularly important since qanats were mostly constructed in the pre-modern era. Moreover, clay makes it possible to keep and convey water through the tunnel as opposed to other types of soil like sand. 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

We aim to explore how the existence of historical qanats associates with cooperative economic activity today at sub-province level within Iran. The data we employ comes from two key sources. We have obtained extensive geographic data on qanats from the Agriculture Ministry of Iran that we put into use for the first time. We have also digitized different provincial documents of Iran's Ministry of Cooperatives, Labour, and Social Welfare to collect information on cooperatives. We supplement this with a plethora of available datasets to control for various aspects of the argument, such as census data from the Statistical Center of Iran and geographic and climatic covariates.

The unique data on qanats of Iran consists of the geographic coordinates of $40,850$ qanats over Iran as part of a project to gather information about all water resources across the country, with the goal of documenting *all* existing operating or non-operating qanats. Figure 2 depicts the coordinates of qanats throughout Iran. Figure 3 zooms into the Northwestern province of East Azerbaijan adjacent to Lake Urumiyeh, the area where qanats originated from, sketching

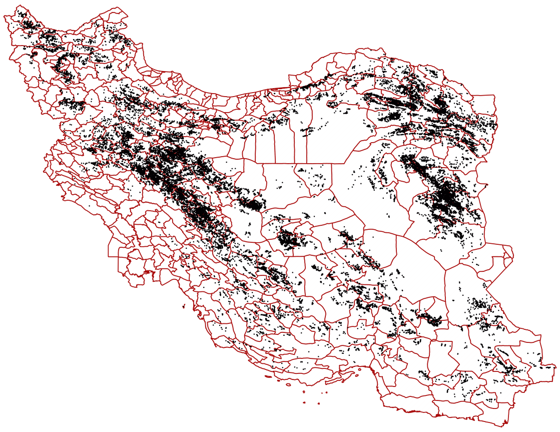


Figure 2: Qanats coordinates across Iran

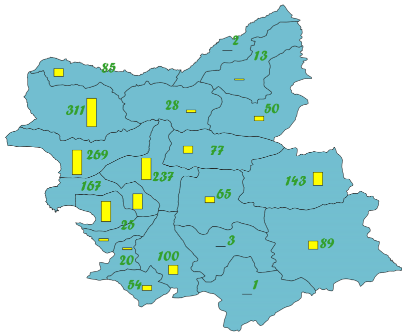


Figure 3: Distribution of Qanats in East Azerbaijan

the number of qanats in each sub-province to demonstrate the details of how qanats are spread across the province.[9]

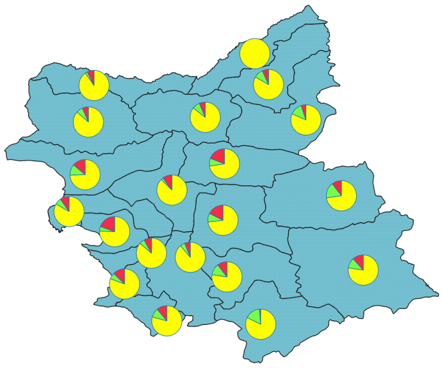


Figure 4: Cooperative companies in East Azerbaijan

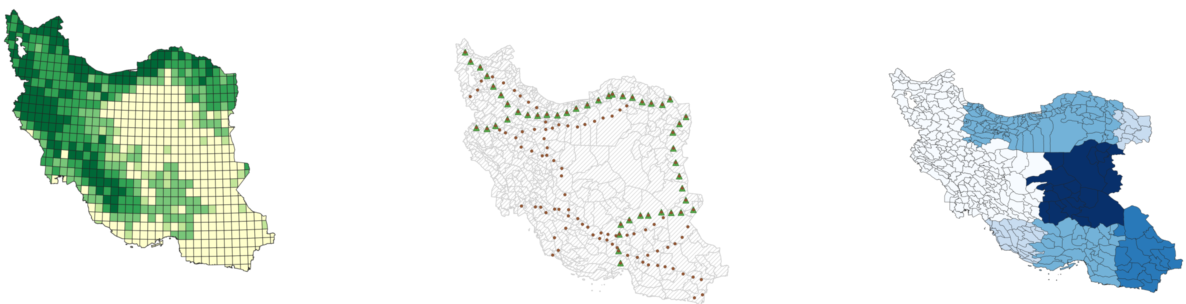
The data on cooperative companies is obtained from the cooperative chapter of the yearly Ministry reports called "statistical yearbook" (*Amarnameh* in Persian) provided for 31 provinces of Iran. However, as this study requires information at a finer level of disaggregation, we obtained data for each of the 429 sub-provinces separately from the respective province office, published in the exact same format. We have collected the reports from each province, digitized the data they contained, and combined them together to have a national dataset. The data digitized refers to the year 2018, which is the last year available at the time of this study. 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. In the cooperative chapter of the reports, cooperative companies are defined in agriculture, industries, construction, housing, services, transportation, and others. 17% of cooperatives are classified as agricultural companies, while 13% are in the industrial sector. As an example, Figure 4 corresponds to Figure 3 and shows the proportion of agriculture (green) and industrial (red) cooperatives in the sub-provinces of East

[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).

Azerbaijan. We are primarily interested in the number of cooperatives, but later also make use of the share of their active members over population. Data on population at the sub-province are from the census collected by the Statistical Center of Iran. We also use the census data to include a number of relevant controls to consider sub-province demographic characteristics on building cooperatives such as literacy and employment rates.

There are a handful of geographical covariates correlated to irrigation, the technology, agriculture, and economic activity, which we control for to isolate the impact of qanats from other geographic characteristics related to the overall environmental suitability for agriculture. For instance, since rainfall reduces dependence on irrigation, we control for mean levels of precipitation. Differences in the access to water sources, such as the rivers, dams and lakes (as a dummy for the existence of other water sources), as well as the average elevation, ruggedness, temperature, and as we will later argue in detail features like slope and the clay content, might also have affected whether or not societies adopted irrigation. 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 (https://www.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 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 green 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. Additionally, we use more comprehensive data including the routes up to 1300 A.D., just before the Safavid era, which experienced a revival of trade and the construction of many new qanats. 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.

	count	mean	sd	min	max
Number of Qanats	429	95.28	183.81	0.00	1740.00
Population Density	422	158.88	633.18	1.31	8380.14
Agriculture cooperatives	413	37.90	52.87	0.00	635.00
Industrial cooperatives	416	27.31	44.26	0.00	353.00
Total cooperatives	412	226.17	478.84	0.00	8024.00
Members of agricultural cooperatives	407	564.93	992.37	0.00	9866.00
Islamic microfinance institutions	429	2.14	7.50	0.00	128.00
Slope	429	3.77	2.65	0.04	13.26
Clay	429	293.56	64.17	150.06	469.10
Land suitability	428	0.14	0.16	0.00	0.79
Distance to trade routes (600)	429	178.09	153.65	3.52	616.83
Climate instability	415	0.20	0.08	0.13	0.37

Table 1: Summary Statistics

5 Empirical Strategy and Baseline Results

5.1 Baseline Specification

To find the relationship between qanats and cooperatives, we first estimate our empirical model 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 is the measure of cooperation culture in sub-province i proxied by number of cooperative companies, Q_i is the demand for cooperation (and the emergence of irrigation communities) proxied by the number of qanats at sub-province i, the X_i are control variables in each sub-province and ε_i is the error term. In order to control for the differences in population across sub-provinces of Iran, we use the number of cooperative companies *per 1000 population* at sub-province level. The number of qanats at each sub-province is also standardized by population because otherwise more populated areas may have a higher number of qanats in absolute terms, which could then result in more cooperatives for reasons different than those argued in the

[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 that encompasses some of the Eastern sub-provinces of Iran.

paper. Initially, we conduct the analysis for cooperative companies in the agriculture sector. We then replicate the exercise for the industrial and the total number of cooperatives in all sectors combined to avoid capturing a potential mechanical relationship between the presence of qanats and agriculture activities.

5.2 OLS Results

In the baseline regressions, we estimate whether the presence of the traditional irrigation technology influences contemporary cooperative activities. The results are displayed in Table 2. Our coefficient of interest, the number of qanats *per 1000 population*, 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, including population density. As it could be expected, a higher level of education in the sub-province is also positively related to the extent of cooperative activities in the region.

	Dependent variable: Number of agricultural cooperatives (per 1,000)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Qanats (per 1,000)	0.024***	0.026***	0.025***	0.025***	0.025***	0.022***	0.033***
	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Pop. dens.			-0.000***	-0.000***	-0.000***	-0.000	-0.000***
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Lit. rate			0.298***	0.294***	0.306***	0.013	0.263***
			(0.073)	(0.073)	(0.081)	(0.163)	(0.097)
Empl. rate			-0.745*	-0.559	-0.489	-0.793	-0.752
			(0.387)	(0.585)	(0.577)	(0.711)	(0.630)
Center prov.			-0.184***	-0.184***	-0.185***	-0.247***	-0.193***
			(0.055)	(0.055)	(0.057)	(0.055)	(0.056)
New subprov.			-0.059	-0.061	-0.061	-0.037	-0.077
			(0.060)	(0.061)	(0.069)	(0.064)	(0.070)
Land suit.				0.077	0.011	-0.074	-0.071
				(0.198)	(0.235)	(0.226)	(0.248)
Dist. trade					-0.000	0.000	-0.000
					(0.000)	(0.000)	(0.000)
Clim. instab.							0.411
							(0.504)
constant	0.346***	-0.038	0.241	0.186	-0.000	-0.000	-0.211
	(0.024)	(0.328)	(0.367)	(0.374)	(0.417)	(0.018)	(0.508)
Geog. Controls	-	X	X	X	X	X	X
Observations	413	413	408	407	407	407	393
Province FE	-	-	-	-	-	X	-

Conley standard errors with 50 km radius in parenthesis. Geographic controls at mean:
annual precipitation, clay content, slope, elevation, ruggedness, temperature and river dummy.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2: OLS regression of number of qanats per 1000 population on agr. cooperatives

Cooperation in the location of qanats is further induced because of other geographic and environmental factors. 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 or outside opportunities to meet irrigation needs are unlikely. This is shown by data, where we control for a dummy variable "Center prov." to indicate whether the sub-province is the capital of a province. A negative and statistically significant coefficient shows that there are less cooperative companies (except for industrial ones) 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.

Given the nature of the data, we also account for changes that occurred in the administrative divisions of Iran since the year 2000. We use a dummy variable "New subprov." to consider issues that related to these political and economic divisions by distinguishing new sub-provinces that could show zero or few cooperative companies in their report because they are newly recognized as a division.[12] As the location of qanats belong to the previous classification of administrative units, the new sub-provinces may underestimate the effect of qanats on the number of cooperatives.

In columns (4) we incrementally control for overall land suitability for crop cultivation. Being close to trade routes made a region attractive to settle as it enabled farmers to also sell their agricultural products outside their localities. Such trade opportunities could induce trust, cooperation, or institutions, and over time lead to the formation of cooperatives. Column (5) adds distance to the nearest trade route as control. In column (6) we control for province fixed effects to capture variation within each province. Interestingly, the number of qanats seem to play a pronounced role in determining the number of cooperative enterprises established within each province, while there tend to be less cooperatives operating at the province capital. In column (7) we replace the province fixed effects with the larger-scale climatic instability measure 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. These findings are interestingly parallel to and confirm the idea in Buggle (2020) on collectivist societies if one perceives cooperatives as less innovative compared to private markets.

We next test the robustness of our estimates by looking at the relationship between qanats and the share of the population in each sub-province who are members of agricultural cooperatives. Doing so is a first attempt to help mitigate concerns that cooperative enterprises along with other firms may have a larger presence in some areas for reasons other than those related to the presence of irrigation systems. In the absence of information about the total number of firms, the ratio of cooperative members directly signals the proportion of population who engage in cooperative activities. Such concerns are further addressed later in the analysis when exploring the correlation between qanats and economic activities measured by population density. Table 3 shows that all results remain identical both qualitatively and quantitatively under all specifications when using this alternative variable.

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

[12] The current sub-province boundaries are a result of major adjustments that took place for political or efficiency purposes, which amount to 83 changes in the universe of our data, mostly up-levelling districts to sub-provinces. After the change, registration of companies (including cooperatives) and institutions do not immediately transfer to the new province or sub-province.

	Dependent variable: Population share of agr. coop. members (per 1,000)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Qanats (per 1,000)	0.262***	0.277***	0.260***	0.262***	0.258***	0.193*	0.337***
	(0.086)	(0.089)	(0.092)	(0.093)	(0.095)	(0.113)	(0.118)
Pop. dens.			-0.001***	-0.001***	-0.001***	-0.002	-0.001***
			(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Lit. rate			4.469***	4.258***	4.514***	-0.896	3.761***
			(1.411)	(1.308)	(1.389)	(2.606)	(1.316)
Empl. rate			-8.066	-1.168	0.344	-7.601	-1.364
			(5.863)	(7.568)	(7.241)	(8.378)	(7.804)
Center prov.			-2.951***	-2.982***	-3.001***	-2.846***	-2.953***
			(0.723)	(0.730)	(0.768)	(0.660)	(0.766)
New subprov.			-1.127	-1.261	-1.240	-0.789	-1.370
			(0.913)	(0.914)	(0.936)	(0.993)	(0.968)
Land suit.				5.485	4.165	1.977	3.559
				(3.622)	(4.298)	(3.954)	(4.437)
Dist. trade					-0.004	-0.000	-0.004
					(0.003)	(0.003)	(0.004)
Clim. instab.							6.950
							(5.919)
constant	4.772***	4.909	8.003	5.675	1.942	-0.000	-1.397
	(0.365)	(4.998)	(5.496)	(5.228)	(6.273)	(0.335)	(7.202)
Geog. Controls	-	X	X	X	X	X	X
Observations	407	407	402	401	401	401	387
Province FE	-	-	-	-	-	X	-

Conley standard errors with 50 km radius in parenthesis. Geographic controls at mean: annual precipitation, clay content, slope, elevation, ruggedness, temperature and river dummy.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: robustness-agr. coop members per 1000 population: OLS

through a process of collective learning to participate in such endeavours. The data used on cooperatives is at province level (44 observations) and derived by looking at the proportion of members over the active male agrarian population in 1923. 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* in 1914. Climatic conditions are used as an instrumental variable as irrigation systems and communities historically developed more in areas with scarce rain-fed cultivability or turbulent climates. Controlling for total irrigated land (as opposed to land irrigated by canals and acequias managed by irrigation communities) aims at separating the direct effect of irrigation on agricultural productivity from the social capital generated by irrigation communities. Doing so, their study shows no statistically significant effect of irrigation to the cooperative movement.

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, we relate to the closest of 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. Traders were obliged to stop at portage sites, creating the opportunity for commerce and supporting services when the dominant form of shipping in the U.S. was waterborne. Population and economic activity continued to thrive at these sites due to path dependence 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 contemporary economic activities remain in locations that pass through once essential nomadic corridors in the highlands. These paths continued to be used as trade routes, along which trade hubs 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 more essential in rather isolated and less densely populated areas. To test this conjecture, in column (1) of Table A.2.1 in the Appendix we replace the dependent variable with population density in our baseline full specification from column (7) of Table 2. We observe no statistically significant correlation between our variable "$Qanat(per 1,000)$" and population density, with a negative coefficient. We can therefore state that qanats are in fact not found in densely populated areas and have therefore not resulted in more cooperatives today by fostering long-run urban development. In columns (2) and (3) instead, we replace population density with our key demographic variables, literacy and employment rates, to assure that they are not bad controls correlated to the presence of qanats, being contemporary variables from the census. Neither variables are correlated with qanats, mitigating collinearity concerns among the predictors.

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. Even if shared land ownership and agricultural cooperatives were only conceded after the reform act of the 1960 and qanats are historical and principally all built before that critical juncture, there may be a number of unobserved factors that might have influenced whether societies adopted cooperative norms. Societies who built qanats may have been more cooperative to begin with due to certain land features also conducive to qanats. From a different perspective, cooperatives may instead be an alternative to markets in less developed areas. We therefore devote the rest of the analysis to building a suitable instrumental variable and use it to estimate the pervasiveness of qanats in each sub-province.

6.1 The 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 qanat on cooperation), we only 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 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 cooperative firms, unless through qanats. However, the main threat to the identification strategy is that irrigation technology could be correlated with other geographic characteristics as omitted variables that affect outcomes 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 with that can equally benefit from qanat irrigation, as the one with more suitable regions with an adequate slope and clay content can accommodate more qanats and incite a greater scale of cooperation.

To build the instrumental variable we first use GIS tools to create grid-level data, dividing Iran to 9km $\times$ 9km grids summing up to circa $21,000$ virtual sub-provinces. Calculating the density of qanats at each grid, figures A.3.1 and A.3.2 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 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. 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.[13] 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 right as a slightly higher clay

[13] We later assess the sensitivity of our results to reasonably extended intervals of slope and clay content.

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.[14]

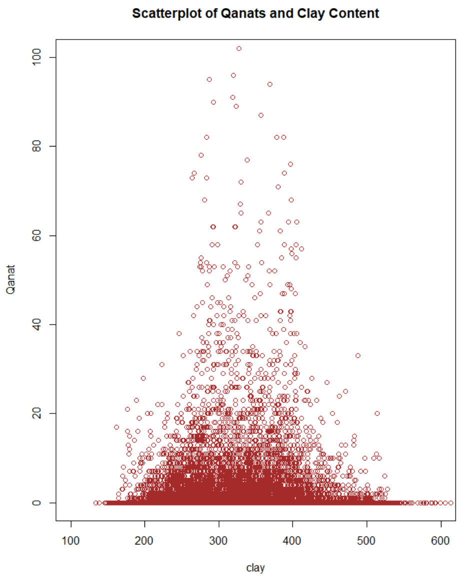


Figure 6: Clay and number of qanats at grid level

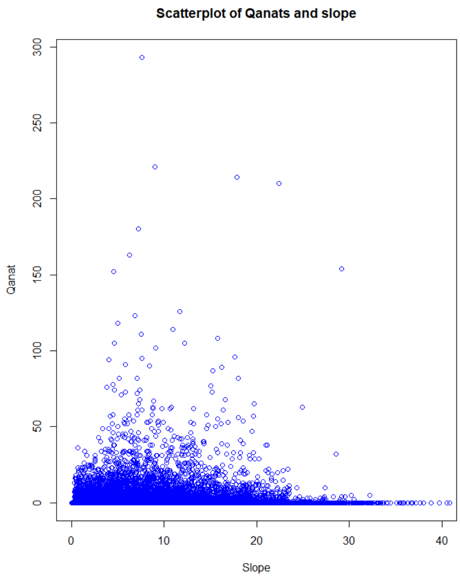


Figure 7: Slope and number of qanats at grid level

An interesting parallel to our IV approach is the work of Duflo and Pande (2007) on large irrigation dams in India. In their study, since regions with more dams are likely to differ along other dimensions like potential agricultural productivity, a mere comparison of outcomes (agricultural production) in regions with and without dams cannot yield a causal estimate. Using geographical suitability for infrastructure of dams from the dam engineering literature as IV, they argue that the gradient at which a river flows affects the ease of dam construction with a low but non-zero slope being most adequate for irrigation dams, and very steep ones for hydroelectric dams. They therefore obtain IV estimates by utilizing variation in dam construction brought about by differences in river gradient across districts within Indian states to obtain IV estimates. The reason for the suitability of a moderate gradient that it allows a long reservoir in proportion to the height of the dam. Also since the system relies on gravity for the flow of water from dams to irrigated areas, a minimal slope is necessary for delivery, but not so much that the velocity erodes the canal. Using these engineering considerations, they show that a gentle river gradient increases the number of irrigation dams, while a steep gradient reduces it. In our case, we added (intermediate) clay content to the engineering grounds above as the geological factor that facilitates the construction of qanats and adjusts an adequate flow of water to irrigation lands. This second ingredient of our IV somewhat 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. Both Carboniferous surface geology and the presence

[14]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 instrument relevance condition to be satisfied.

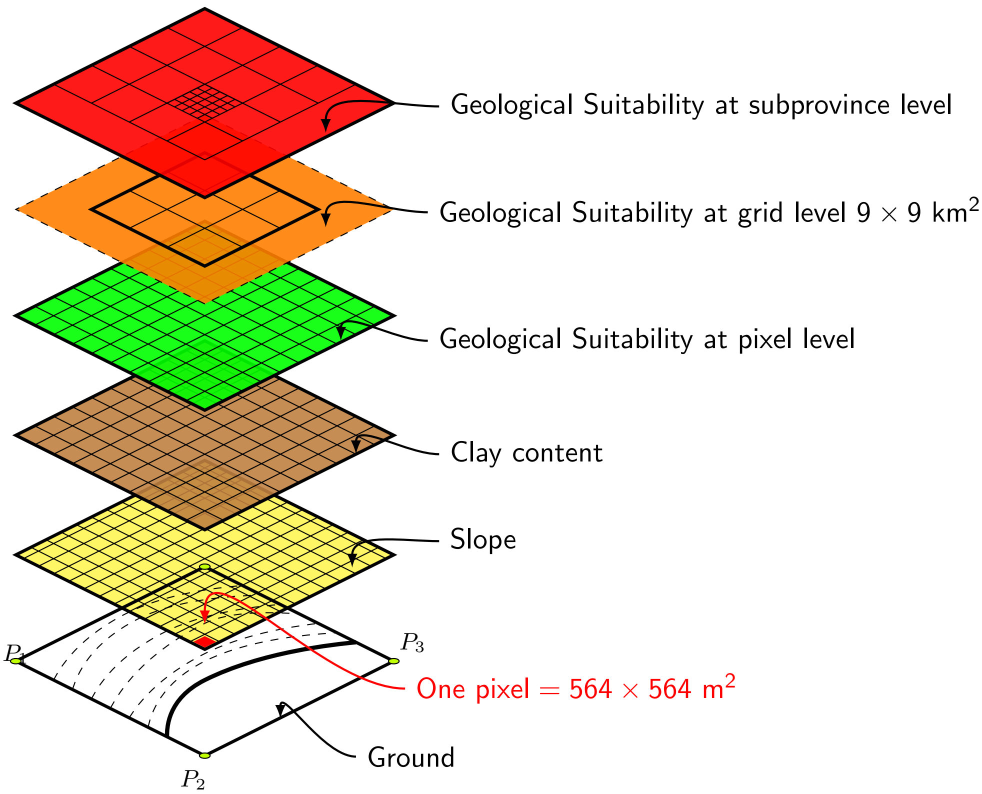


Figure 8: Topology of Land for Irrigation

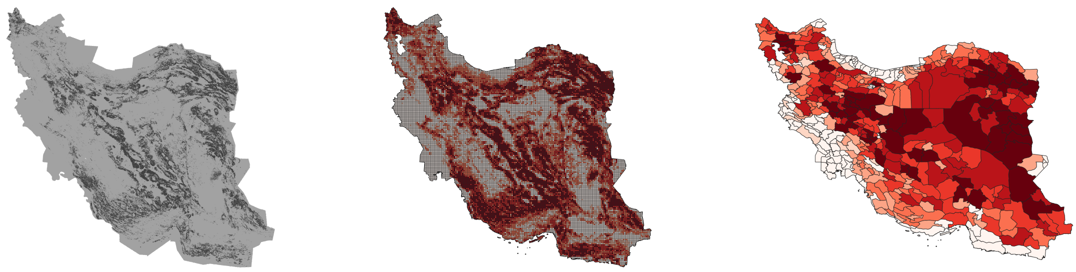
of coal deposits therein are used as a predictor of historical coal mines as they facilitated the discovery and extraction of coal.

The construction of our IV is schematically illustrated in figure 8. The bottom-most layer in the figure shows a hypothetical piece of ground. This layer is then 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 $564 \times 564 m^2$). 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 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 analysis 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 further aggregate 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 reduced form regression (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 (per 1,000) 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 by population. Otherwise if a more proportion of qanat-suitable land also implies more cultivable populated land, then the exclusion restriction could be violated. Doing so also accounts for demand and social feasibility of this irrigation technology. 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). Thus, in sparsely populated areas demand for qanats is large and coordination and scale management is feasible.[15] 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).[16] 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 grey represent unsuitable areas and the degree of suitability increases from light to dark red. The third panel of the figure instead shows a heat map of the actual intensity of qanats in each sub-province, again with darker colors indicating a higher density of qanats per population.

6.2 Instrumental Variable Baseline Results

Since we established that the OLS results might potentially be biased due to the endogeneity of the irrigation technology, we use the instrumental variable method described in the previous section to deal with this caveat. To begin, the first-stage results in Table 4 illustrate that 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.

[15] Allen et al. (2022) for instance measures the severity of the collective action problem in coordinating and jointly managing canal irrigation by counting the number of settlements in a grid.

[16] 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.

The rest of Table 4 replicates Table 2 and shows that the IV regressions confirm the OLS results.[17] In all specifications, the coefficient of interest on the estimate of qanats is statistically significant and the sign is positive, confirming our original findings. Our results remain intact also when controlling for province fixed effects, and under our full specification.[18] Finally as explained earlier, new sub-provinces tend to have a negative coefficient because newly-recognized divisions may not yet have the cooperative companies registered and documented there.

First-stage	*Dependent variable:* Qanats (per 1,000)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Geol. suit.	267.149***	217.633***	219.005***	262.470***	262.217***	208.055***	233.625***
	(76.375)	(68.835)	(68.275)	(74.702)	(74.930)	(44.672)	(70.849)
constant	0.588***	-2.552	-1.210	-2.779	-2.864	0.000	-3.682
	(0.149)	(1.575)	(1.844)	(1.894)	(2.066)	(0.109)	(2.568)
Second-stage	*Dependent variable:* Number of agricultural cooperatives (per 1,000)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Qanats (per 1,000)	0.104***	0.143***	0.169***	0.170***	0.169***	0.163***	0.192***
	(0.029)	(0.040)	(0.051)	(0.050)	(0.050)	(0.045)	(0.058)
Lit. rate			0.142	0.136	0.142	0.144	0.137
			(0.105)	(0.110)	(0.108)	(0.137)	(0.134)
Empl. rate			-0.959	-0.887	-0.857	-1.547	-1.516
			(0.614)	(0.913)	(0.922)	(0.969)	(1.074)
Center prov.			-0.035	-0.037	-0.039	-0.118	-0.030
			(0.078)	(0.079)	(0.078)	(0.074)	(0.077)
New subprov.			-0.159*	-0.162*	-0.161*	-0.151**	-0.197**
			(0.090)	(0.090)	(0.090)	(0.076)	(0.095)
Land suit.				0.146	0.114	0.066	0.022
				(0.225)	(0.241)	(0.235)	(0.244)
Dist. trade					-0.000	0.000	-0.000
					(0.000)	(0.000)	(0.000)
Clim. instab.							-0.060
							(0.668)
constant	0.243***	0.051	0.488	0.452	0.363	-0.000	0.283
	(0.035)	(0.361)	(0.423)	(0.448)	(0.530)	(0.025)	(0.706)
Geog. Controls	-	X	X	X	X	X	X
Observations	412	412	412	411	411	411	397
Province FE	-	-	-	-	-	X	-
F-test (first-stage)	11.711	9.528	9.668	11.497	11.362	20.308	10.045

Conley standard errors with 50 km radius in parenthesis. Geographic controls at mean: annual precipitation, clay content, slope, elevation, ruggedness, temperature and river dummy.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: IV regression of number of qanats per 1000 population on agr. 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 estimated in Tables 2 and 4 with data for

[17]Note that population density cannot be included as control in the IV regressions as the IV inherently captures both area and population in the denominator.

[18]We also perform our baseline IV regressions for the share of cooperative members over population as dependent variable in table A.4.1 of the Appendix, which produces the same results.

cooperative companies at the industrial sector and also the sum of all cooperative companies (of any type). The coefficients behave in a similar manner and the qualitative findings remain the same. Table 5 illustrates the full baseline specification OLS and IV estimates for industrial cooperatives in columns (1)-(2) and for total cooperatives in columns (3)-(4). We observe also more non-agricultural cooperatives today in locations where qanats were historically built. This further reduces the concern that agricultural cooperatives were built for the purpose of making irrigation functional in their local regions. Instead, there is more of any type of cooperative enterprise as a proxy for social capital in locations where the culture of cooperation was developed due to the existence of qanats.

	Dependent variable: Nr. of cooperatives (per 1,000)			
	(1)	(2)	(3)	(4)
	industrial	industrial	total	total
	(OLS)	(IV)	(OLS)	(IV)
Qanats (per 1,000)	0.018***	0.059***	0.108***	0.701***
	(0.003)	(0.021)	(0.037)	(0.223)
Pop. dens.	-0.000***		-0.000***	
	(0.000)		(0.000)	
Lit. rate	0.098	0.065	0.754	0.491
	(0.153)	(0.150)	(0.605)	(0.675)
Empl. rate	0.377	0.122	-5.670*	-9.550**
	(0.427)	(0.459)	(2.919)	(4.738)
Center prov.	-0.022	0.017	-0.568***	-0.109
	(0.038)	(0.046)	(0.199)	(0.263)
New subprov.	-0.114***	-0.153***	-0.433*	-0.994***
	(0.030)	(0.038)	(0.237)	(0.347)
Land suit.	-0.068	-0.063	-0.112	0.182
	(0.124)	(0.124)	(0.749)	(0.775)
Dist. trade	-0.000	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.001)	(0.001)
Clim. instab.	0.754**	0.621*	1.155	-0.951
	(0.353)	(0.325)	(1.252)	(1.999)
constant	-0.285	-0.157	4.559**	6.465**
	(0.298)	(0.293)	(2.271)	(2.962)
Geog. Controls	X	X	X	X
Observations	396	400	383	386

Conley standard errors with 50 km radius in parenthesis.
Geographic controls at mean: annual precipitation, clay content, slope, elevation, ruggedness, temperature and river dummy.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Regression of number of qanats per 1000 population on ind. and total cooperatives

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.5.1 of the Appendix, we perform the test for 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 on 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 its impact on the emergence and adoption of the cooperation is a historical question, it is essential that we touch upon a number of episodes in history 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 in determining our outcome. We now shed light on whether trade opportunities instead contributed in the persistence of cooperation that stems from qanats by investigating the interaction between 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.

	Dependent variable: Nr. of cooperatives (per 1,000)					
	(1)	(2)	(3)	(4)	(5)	(6)
	Agr.	Agr.	Agr.	Agr.	Ind.	Total
Qanat (per 1,000)	0.286***	0.520*	0.247***	1.041**	0.260*	1.791***
	(0.085)	(0.307)	(0.077)	(0.450)	(0.133)	(0.617)
Lit. rate	0.307***	0.260	0.157	-0.038	0.027	0.236
	(0.100)	(0.160)	(0.131)	(0.239)	(0.165)	(0.742)
Empl. rate	-1.271	-1.135	-1.754**	-1.991	-0.001	-8.182**
	(0.922)	(1.281)	(0.865)	(1.305)	(0.485)	(3.805)
Center prov.	-0.138*	0.026	-0.197***	-0.090	0.001	-0.349
	(0.075)	(0.153)	(0.063)	(0.100)	(0.043)	(0.221)
New subprov.	-0.176**	-0.133	-0.104	-0.215*	-0.158***	-0.647**
	(0.089)	(0.135)	(0.072)	(0.126)	(0.043)	(0.263)
Land suit.	0.229	0.360	-0.003	0.358	0.015	0.490
	(0.255)	(0.399)	(0.223)	(0.323)	(0.136)	(0.796)
Dist. trade (600)	0.001**		0.001***	0.002*	0.000	0.004***
	(0.000)		(0.000)	(0.001)	(0.000)	(0.001)
Dist. trade (600)× Qanat	-0.001***		-0.001***	-0.002**	-0.001*	-0.004***
	(0.000)		(0.000)	(0.001)	(0.000)	(0.001)
Dist. trade (1300)		0.006*				
		(0.003)				
Dist. trade (1300)× Qanat		-0.004*				
		(0.002)				
Clim. instab.				4.987**	1.811**	8.244***
				(2.295)	(0.767)	(3.163)
Clim. instab.× Qanat				-2.064**	-0.479	-3.470**
				(0.958)	(0.299)	(1.581)
constant	0.564	0.501	-0.000	-2.636*	-0.840*	0.868
	(0.535)	(0.649)	(0.022)	(1.448)	(0.502)	(2.969)
Geog. Controls	X	X	X	X	X	X
Observations	411	411	411	397	400	386
Province FE	-	-	X	-	-	-

Conley standard errors with 50 km radius in parenthesis. Geographic controls at mean:
annual precipitation, clay content, slope, elevation, ruggedness, temperature and river dummy.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: IV regression of the interaction of qanats per 1000 population with trade and climatic instability on agr. cooperatives

One can think that ancient trade routes induced qanat construction to provide water and services to merchants. It is also plausible to think that historical qanats were responsible for the development of settlements, who built trade routes to transport their supplies to outside markets. The irrigation technology may have as well traveled along the trade routes, spreading the skills to neighbouring regions. In what follows, we argue the mentioned trade channels do not cause but may contribute to the persistence of the qanat-induced cooperation culture.

Our main specification will hereafter include the two interaction terms "$Dist.trade \times Qanat$" and "$Clim.instab. \times Qanat$". Looking at the first columns of Table 6, The positive coefficient of distance suggests that proximity to trade routes does not necessarily lead to a higher concentration of agricultural cooperatives today, contrary to the notion that it stimulates the development of trust, cooperation, or institutions. However, the negative coefficient of the interaction term suggests that cooperation culture in areas abundantly endowed with qanats tend to persist *close* to trade routes. Column (2) shows that the argument is robust to considering the expansion of trade routes up until 1300 A.D., although to a lesser degree of significance. Going back to the 600 A.D. trade routes, which we believe are the most likely to be exogenous, we can observe in column (3) that the aforementioned relation also holds within sub-provinces.

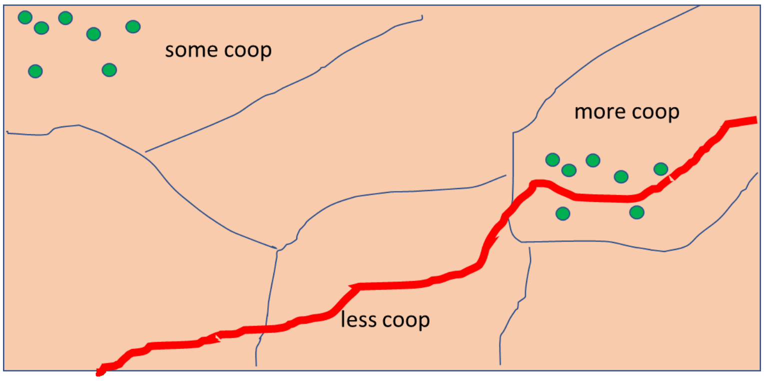


Figure 10: The Role of Trade and Qanats on Cooperation

The results are illustrated in Figure 10. The red line and the green dots represent a trade route and qanats, respectively. This leads us to the potential interpretations of the involvement of trade routes with qanats that shed light on how they may have impacted cooperation. If trade routes preceded qanats, which is most likely to be the case for our 600 A.D. trade route data, the importance of qanats for the subsistence of trade hubs and caravanserais in arid regions reinforced the cooperation culture. Even if qanats nurtured communities who sought trade, the results suggest that being close to routes contributed to the persistence of the qanat-induced cooperation culture. Considering instead the hypothesis that qanats spread via trade routes, the cooperation culture flourished and persisted only in geographies along the routes where qanats were needed and feasible. Under all scenarios, sub-provinces close to trade routes that do not host a large number of qanats do not reveal a higher number of cooperative firms today.

Looking at trade routes allows us to look at possible channels through which trade interacted with qanats to contribute to the persistence of the cooperation culture over time. We saw potential mechanisms through which trade opportunities only reinforced our original argument despite trade and the creation of trade routes being a continuous event that has occurred after the invention and during the construction of qanats. Nonetheless, it remains a challenging task to argue the persistence of the cooperation culture nurtured by the socioeconomic aspects of qanats, in the form of social capital and cooperative enterprises today.[19] 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 (4)-(6) of Table 6 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 not only support the findings discussed regarding trade, they also confirm the notion of cultural persistence put forth in the thesis of Giuliano and Nunn (2021). We observe the persistence of this cooperation culture 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 regions: placing cooperation created through 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 do not experience severe variability in climate across generations. 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. 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, we replicate our full OLS specification in Table 2 and show 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 obtained information about the more familiar measure of trust. The 7th round of the WVS (2017 – 2021) allows us to geo-locate 133 towns across Iran, where the survey was conducted. We believe the question most relevant as an outcome of the qanat culture is how much individuals trust people from their neighbourhood. Here, we create a dummy variable

[19] 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.

that is equal to one if participants somewhat or completely trust their neighbour, and zero if they do not trust their neighbours much or at all. Importantly, this level of analysis 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.

To conduct the estimates, we need to assess whether a higher number of qanats in the survey location leads the members of a community to feel more trust towards their neighbours. Given the more granular level of this last test, we revisit our original data on qanats, and count the number of qanats within a 50km buffer of the location where the survey was conducted. The map in Figure 11 depicts again qanats in Iran together with the buffered areas around the 133 survey locations. Doing so also allows us to calculate suitability of land for agriculture in each buffered area as another key control variable. The results are presented in Table 8 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 stanard 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).

	Dependent variable: Nr. of Islamic non-profit microfinance *Qard al-Hasan* institutes						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Qanats (per 1,000)	0.002***	0.001***	0.001***	0.001***	0.001***	0.001**	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Pop. dens.			0.000	0.000	0.000	-0.000***	0.000
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Lit. rate			0.014	0.014	0.014	0.008	0.010
			(0.009)	(0.009)	(0.009)	(0.009)	(0.008)
Empl. rate			0.039	0.071**	0.068**	0.031	0.059*
			(0.031)	(0.034)	(0.034)	(0.030)	(0.034)
Center prov.			-0.004*	-0.004*	-0.004	-0.005**	-0.003
			(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
New subprov.			-0.005**	-0.006**	-0.006**	-0.006***	-0.007**
			(0.002)	(0.002)	(0.003)	(0.002)	(0.003)
Land suit.				-0.001	0.001	-0.007	-0.001
				(0.008)	(0.009)	(0.010)	(0.009)
Dist. trade					0.000	-0.000	0.000
					(0.000)	(0.000)	(0.000)
Clim. instab.							0.032
							(0.021)
constant	0.010***	0.026**	0.010	0.002	0.007	0.000	-0.008
	(0.001)	(0.013)	(0.017)	(0.017)	(0.018)	(0.001)	(0.021)
Geog. Controls	-	X	X	X	X	X	X
Observations	429	429	422	421	421	421	407
R^2	0.061	0.085	0.122	0.130	0.132	0.090	0.159
Province FE	-	-	-	-	-	X	-

Conley standard errors with 50 km radius in parenthesis. Geographic controls at mean:
annual precipitation, clay content, slope, elevation, ruggedness, temperature and river dummy.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: OLS: Islamic non-profit microfinance Gharzolhasane Institutes

The local nature of this test also allows us to exploit further information from the qanat data, namely whether they are still active or abandoned, to use the latter group as a placebo test. Note

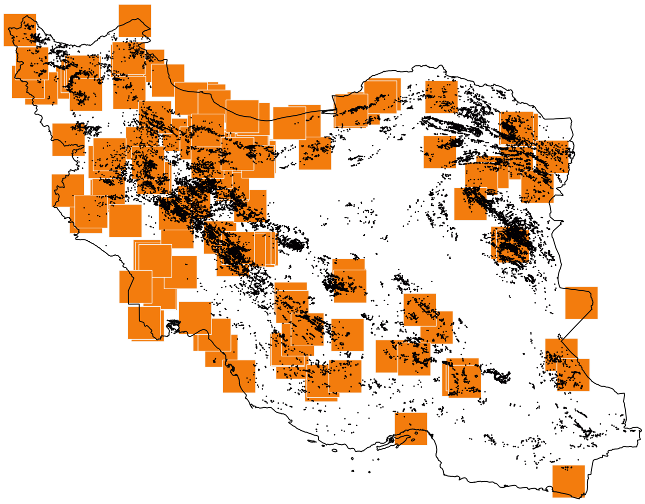


Figure 11: Qanats and Trust in Neighbours

	Dependent variable: trust in people from neigborhood						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Nr. Qanats	0.00004**	0.00004***	0.00004***	0.00004**	0.00004***		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
Active ratio						0.04704***	
						(0.008)	
Inactive ratio							0.00211
							(0.013)
Age	0.00519***	0.00519***	0.00532***	0.00519***	0.00563***	0.00546***	0.00545***
	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Gender	-0.06597***	-0.06597***	-0.06012***	-0.06597***	-0.06912***	-0.07011***	-0.07004***
	(0.021)	(0.018)	(0.015)	(0.019)	(0.020)	(0.020)	(0.020)
Settl. size	-0.02636***	-0.02636***	-0.02669***	-0.02636***	-0.02900***	-0.02701***	-0.02735***
	(0.007)	(0.008)	(0.008)	(0.005)	(0.001)	(0.001)	(0.001)
Land suit.	0.09708	0.09708	0.24064	0.09708	0.35701***	0.34630***	0.31055***
	(0.098)	(0.113)	(0.177)	(0.125)	(0.007)	(0.006)	(0.003)
constant	0.74289***	0.74289***	0.71311***	0.74289***	0.70785***	0.70101***	0.74140***
	(0.051)	(0.042)	(0.036)	(0.050)	(0.049)	(0.052)	(0.053)
Observations	1493	1493	1493	1493	1493	1342	1342
R^2	0.053	0.053	0.055	0.053	0.056	0.055	0.055
Ethnic clust.	-	X	X	-	-	-	-
Ethnic FE	-	-	X	-	-	-	-
Town clust.	-	-	-	X	X	X	X
Town FE	-	-	-	-	X	X	X

Standard errors in parentheses
Questionnaire: How much do you trust people from your neighborhood?
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 8: OLS: Impact on trust in society

that the same analysis could not be conducted at the sub-province level as the large numbers of both active and inactive qanats in vast provinces would make the comparison meaningless. Nonetheless, the use of this feature must only be treated as suggestive evidence because the use of qanats could have been discontinued throughout history for many reasons other than the lack of cooperation. It could however be informative about areas, where cooperative institutions emerging from qanats failed in certain areas prior to their transformation into culture. Columns (6) and (7) confirm our theory and show that trust in neighbours is only present for the ratio of active qanats and uncorrelated with the ratio of inactive qanats in the area.

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 obtained detailed data on Persian qanats from the Agricultural Ministry of Iran. The dataset is the collection of geographic coordinates of all qanats across 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 use of qanats and cooperative companies today in Iran. 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.

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 believe this is another step forward in confirming the validity of our proposed mechanism on how this ancient irrigation system could lead to a higher level of social capital observed today.

The necessity for cooperation in the case of qanats further stretches because of the continuous need for maintenance. Looking at maintenance from another point of view, it also strengthen the persistence of the effect. While qanats may have been constructed hundreds of years ago, the users need to cooperate together as long as they operate and the users are extracting water. 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 opens the way to extend our research in several directions that can better exploit the level of granularity of the data. These 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

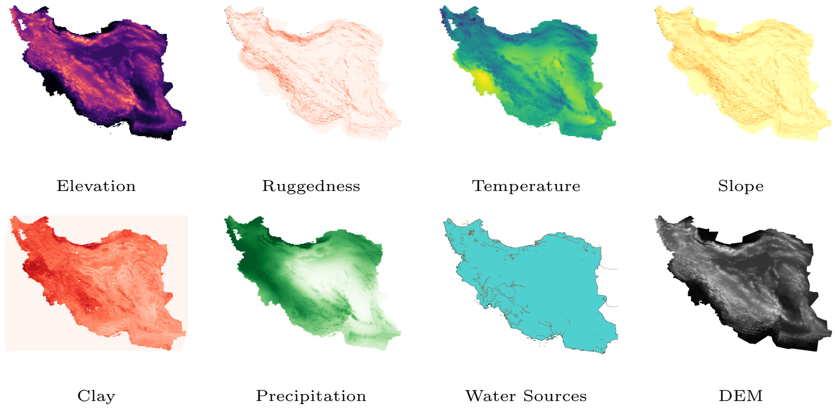

Figure A.1.1: Geographic Data

A.2 Qanats and Population Density

	Dependent variable:		
	Pop. dens.	Literacy rate	Employment rate
Qanat (per 1,000)	-26.068	0.002	0.000
	(21.381)	(0.002)	(0.001)
Pop. dens.		0.000***	0.000**
		(0.000)	(0.000)
Literacy rate	356.109		0.029*
	(271.626)		(0.016)
Employment rate	927.656	0.724***	
	(660.685)	(0.278)	
Center prov.	284.036*	0.076***	-0.010**
	(146.792)	(0.025)	(0.004)
New subprov.	184.527	-0.008	0.002
	(156.081)	(0.016)	(0.005)
Land suitability	696.823	0.066	-0.042***
	(508.288)	(0.070)	(0.013)
Dist. trade	-0.265	0.000**	0.000
	(0.371)	(0.000)	(0.000)
Clim. instab.	-64.220	0.684***	-0.036
	(303.216)	(0.183)	(0.031)
constant	280.108	-0.006	0.347***
	(335.304)	(0.273)	(0.035)
Geog. Controls	X	X	X
Observations	421	421	421

Conley standard errors in parenthesis.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.2.1: Population density

A.3 Qanat Map at Sub-province and Grid Level

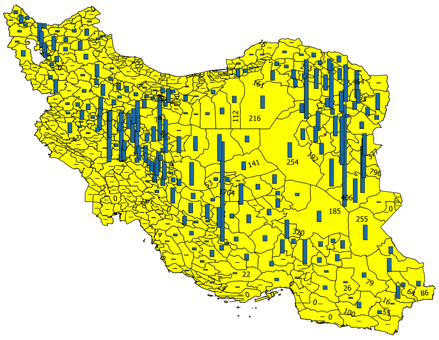

Figure A.3.1: Qanat Count at sub-provinces

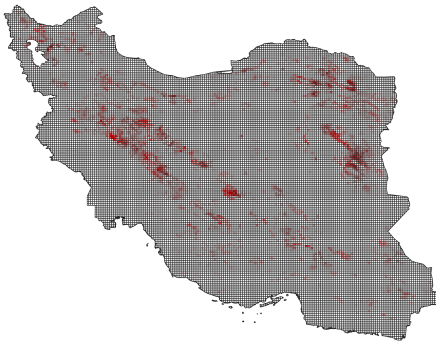

Figure A.3.2: Gridded map of Iran $9km \times 9km$

A.4 IV: Members in Agricultural Cooperatives as the Share of Population

	Dependent variable: Population share of agr. coop. members (per 1,000)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Qanats (per 1,000)	1.354**	1.850**	2.169**	2.251**	2.229**	2.535**	2.530**
	(0.557)	(0.740)	(0.886)	(0.878)	(0.904)	(1.078)	(1.039)
Lit. rate			2.289*	1.952	2.111	1.229	1.895
			(1.362)	(1.372)	(1.316)	(2.981)	(1.549)
Empl. rate			-10.784	-5.869	-5.066	-19.428	-12.264
			(8.157)	(11.811)	(11.342)	(15.045)	(14.009)
Center prov.			-0.962	-0.967	-1.007	-0.929	-0.703
			(1.163)	(1.166)	(1.078)	(1.096)	(1.103)
New subprov			-2.546**	-2.766**	-2.743**	-2.759*	-3.167**
			(1.291)	(1.304)	(1.336)	(1.512)	(1.433)
Land suit.				6.300	5.489	3.704	4.811
				(3.989)	(4.629)	(4.414)	(4.703)
Dist. trade					-0.002	0.004	-0.005
					(0.003)	(0.005)	(0.004)
Clim. instab.							0.098
							(8.620)
constant	3.354***	5.685	10.794*	8.863	6.654	-0.000	5.350
	(0.640)	(5.422)	(6.399)	(6.486)	(7.481)	(0.427)	(9.724)
Observations	407	407	407	406	406	406	392
Geog. Controls	-	X	X	X	X	X	X
Province FE	-	-	-	-	-	X	-

Conley standard errors with 50 km radius in parenthesis. Geographic controls at mean: annual precipitation, clay content, slope, elevation, ruggedness, temperature and river dummy.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.4.1: IV regression of population share of agr. cooperatives (per 1,000)

A.5 IV Sensitivity Analysis

	Dependent variable: Nr. of cooperatives (per 1,000)		
	(1) Agr.	(2) Ind.	(3) Total
Qanat per (1,000)	0.187***	0.065***	0.555**
	(0.061)	(0.024)	(0.245)
Lit. rate	0.141	0.062	0.540
	(0.132)	(0.150)	(0.636)
Empl. rate	-1.495	0.099	-8.735**
	(1.087)	(0.486)	(4.395)
Center prov.	-0.035	0.023	-0.236
	(0.083)	(0.048)	(0.251)
New subprov.	-0.194**	-0.157***	-0.874**
	(0.092)	(0.039)	(0.342)
Land suit.	0.018	-0.058	0.071
	(0.236)	(0.123)	(0.742)
Dist. trade	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.001)
Clim. instab.	-0.043	0.603*	-0.418
	(0.662)	(0.337)	(1.859)
constant	0.266	-0.138	5.976**
	(0.720)	(0.306)	(2.811)
Geog. 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 in parenthesis. Geographic controls at mean:
annual precipitation, clay content, slope, elevation, ruggedness, temperature and river dummy.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.5.1: IV robustness