The Role of Irrigation in the Development of American Agriculture

Eric C. Edwards, Utah State University
Steven M. Smith, Haverford College

Abstract:
Starting in the 1930s, agriculture in the US underwent a productivity revolution. We examine the role of irrigation in the marked increase in farm productivity and distinguish the effects of surface water from groundwater. The Bureau of Reclamation expanded surface water infrastructure immensely beginning with the completion of the Hoover Dam in 1936. Meanwhile, rural electrification and the advent of the center pivot expanded use of groundwater as well. The development of each has been studied in isolation, but not in an integrative analysis. We use data from the US agricultural census to track measures of irrigation along with measures of farm productivity from 1900 on. To statistically identify the effect of irrigation, we compare counties before and after 1940 based on their potential access to surface water and groundwater defined by physical characteristics. Results indicate that groundwater increases irrigated acreage and income more than large surface water projects, but surface water remains more productive.

Keywords: Agricultural production; irrigation; groundwater; surface water

JEL: Q15, Q25, O13, N52

I. Background

Starting in the 1930s, agriculture in the United States underwent a productivity revolution. Countrywide crop output per acre was stagnant from 1900 until around 1935, but then increased at an average of 2.1% per year for the next 60 years (Gardner 2002, p. 22). Many explanations have been offered for the production shift, including modernization of equipment and chemicals (Rasmussen 1962), regulatory changes (Clarke 1994), and the electrification of farms (Lewis and Severnini 2014; Kitchens and Fishback 2015). We examine the role of irrigation in the marked increase in farm productivity, particularly in the western United States. Today, although only 7.5 percent of cropland and pastureland in the US is irrigated, it provides nearly 55 percent of total value of crop sales, suggesting an important role in overall agriculture productivity (USDA, 2013).

Like agriculture productivity as a whole, irrigated acreage in the western US remained relatively stagnant during the early 20th century. From 1920 to 1940 total acreage irrigated hovered around 20 million acres (see Figure 1). By 1978 the figure had more than doubled to over 40 million acres of irrigated land. Bretsen and Hill (2006) attribute the growth to Irrigation Districts and their ability to reduce the transaction costs in financing shared infrastructure. Irrigation Districts, along with the Federal support from the Bureau of Reclamation, came about at the turn of the 20th century, but the growth in irrigated acres did not come until after the 1940s. This aligns with the dam-era, beginning with the Hoover Dam's completion in 1936, expanding surface water storage from negligible amounts to over 30 million acre-feet by 1978.

However, this is only half the story. Shown in Figure 1, irrigated acreage expanded even more so under the “individual/partnership” enterprise type from 1940 to 1978. Though smattered with small surface water enterprises of 5 or fewer farmers, the growth in this category can be attributed to groundwater users. With rural electrification (1935-1955) and the advent of the center pivot in 1948, use of groundwater beneath farms became economical. New access to groundwater over the Ogallala aquifer resulted in a $26 billion increase in value relative to farms near, but without access to the aquifer (Hornbeck and Keskin 2015).

The development of each, surface water and groundwater, have been studied in isolation, but not in an integrative analysis. This paper examines how much the source of irrigation water matters in the development of agriculture in the western US. We expect differences due to past development patterns as well as the distinct issues that confront surface water users and groundwater users. Surface water storage requires immense capital; groundwater storage is free. Surface water requires cooperation with neighbors to deliver and divide the water, though the water itself is generally free. Groundwater users require no cooperation and can develop the source independently, though face costs in pumping the water. Surface water availability is uncertain year-to-year owing to climactic conditions and the prior appropriation doctrine while groundwater users are able to extract independent of climactic and institutional limitations. However, groundwater users may face challenges due to common-pool resource properties. In fact, those over the Ogallala saw the premium reduced from $26 billion to $9 billion as the aquifer storage was reduced (Hornbeck and Keskin 2015).

To empirically quantify and test and the impact of the alternative sources of irrigation water, we use data from the US agricultural census to track measures of irrigation adoption along with farm income, land values, and other measures of farm productivity from 1900 to 1978. To statistically identify the effect of irrigation, we compare counties before and after 1940 based on their potential access to surface water and groundwater defined by physical characteristics. For surface water we extract the highest order stream segment from the National Atlas of the US (2014) within the county borders and bifurcate the counties by high (4-7) and low (1-3) stream types. Figure 2 shows that this division generally captures the development of surface water storage projects, with most of the expansion occurring in the high surface water counties. For groundwater access we calculate a continuous measure capturing the percent of the county overlaying an aquifer as located by the US Geological Service (2003). Figure 3 shows how wells through 1950, the last year where well data is available, for four categories of water availability, the counties with high groundwater availability add more wells, with a marked uptick after 1940.

Using the measures of surface and groundwater availability, we conduct a triple-difference analysis, defining the treatment period as after 1940. As discussed above, the large development of both ground and surface water occurs soon after 1940. Although there is some development prior to that year, the time period and physical measures predict irrigated acreage by enterprise quite well. In Figure 4 we show the acreage irrigated by Irrigation Districts for states that have the most surface water compared to those with the least, according to the stream order predictor we construct. Both follow a similar trend until 1950, when irrigated acreage expands noticeably more in states with

larger rivers. Similarly, for States with more groundwater access, Figure 5 shows the dramatic increase in the land irrigated under the "individual" irrigation enterprise.

Results indicate that groundwater access in a county created the largest gains post-1940: increasing percent of land irrigated, crop production, and ultimately farm values. However, access to surface water, on average, still commands higher values, but this premium is driven by development prior to large western irrigation projects. The results are more nuanced for those counties that enjoy access to both surface and ground water. Furthermore, it remains that access to water directly from the sky remains the most valuable; the eastern US maintains a premium above western counties even after the widespread development of irrigation. These results inform current policy debate on agricultural productivity in the developing world: irrigation is only a partial substitute for precipitation; and, if the low-cost irrigation development has already occurred, the marginal benefit of groundwater irrigation may be much larger than the creation of large surface water projects.

II. Data

We utilize U.S. agriculture and irrigation census data at the county level for the 17 western states, generally considered to be the arid region of the country: Washington, Oregon, California, Nevada, Idaho, Montana, Utah, Arizona, Wyoming, Colorado, New Mexico, Texas, North Dakota, South Dakota, Nebraska, Oklahoma, and Kansas. To address the climactic range of the Plain states, we limit the sample to counties west of the 98th meridian, a common approximation of the transition from the sub-humid to the semi-arid portion of the US. Because our economic data spans a significant portion of the 20th century, we fix county borders in 1910 (Minnesota Population Center 2006) and then

reweight data. For instance, using shape files from the *National Historical Geographic Information System* we first use ArgGIS to compute the percent of the 1920 county that is within a 1910 county border. We then reweight the 1920 county data by this percentage before summing over all 1920 counties within the 1910 borders. For the process to yield accurate aggregations in all cases, the census farming data would need to be uniformly distributed over space. Though this unlikely on the whole, most instances are of a single county being divided into two counties in which case the aggregation is accurate even independent the spatial distribution of farms and irrigation.

We utilize data from the US census of Agriculture to look at farmland (and building) values, crop production, and irrigated acreage from 1900-1974. Variables included are described in table 2. Elevation, soil quality, slope, and precipitation data are area averages of each 1910 county shape. Surface water availability comes from Strahler Order, which is a measure from 1 to 7 calculated as follows: a stream with no tributaries is order 1, if two order 1 streams merge, that stream is order 2. If an order 1 and order 2 stream merge, the stream is still order 2, while if two order 2 stream merge, it is order 3, and so on. Economic data is from the US agricultural census as digitized by Haines (2010). Table 1a shows summary statistics for the left-hand side variable, and 1b breaks these statistics out by period and water availability.

III. Empirical Model

To test our hypotheses and ultimately the differential influence of groundwater and expanded surface water access we would run the following regression:

$$\log(\mathrm{Y_{it}}) = \alpha + f(S_{it}, \mathrm{G}_{it}; \boldsymbol{\beta}) + g(\mathbf{L_{it}}, \mathbf{C_i}, \mathbf{T_t}; \boldsymbol{\theta}) + \mathrm{u_{it}}$$

Where Y_{it} is the average value of farm land in county *i* in year *t*. As laid out, we expect this to be a function of surface water storage (S_{it}) and the number of wells drawing on groundwater sources (G_{it}), including possible interactions between the two sources of water. In addition, value is impacted by a number of other attributes, both observed and unobserved, that vary by county and year ($\mathbf{L_{it}}$ – precipitation, population, access to markets, etc.), that vary only by county ($\boldsymbol{C_i}$ – soil quality, latitude, elevation, etc.), and that vary only by year ($\mathbf{T_t}$ – crop prices, technology, financial markets, etc.).

Empirical estimation of the equation is difficult for two reasons. First, the location of wells and reservoirs are unlikely to be random in space or time. The second difficulty is data availability. After the 1950 census there is no longer information reported on the number of wells drawing groundwater. For both 1950 and 1959 the census does provide the number of irrigated acres at the county level by water source (a total in the 17 Western States of 9,349,538 and 12,998,250 acres respectively) but is not reported in other years.[1] Similarly, data on the number of acres irrigated with Bureau of Reclamation water at the county level are only available in 1910 and 1950. Besides the limited availability, using irrigated acreage to define access is itself problematic since irrigators can choose to apply more water to existing acreage or expand acreage. And while we could construct treatment by the presence of a Bureau of Reclamation dam and reservoir, these projects can often be servicing land in counties downstream.

To overcome both issues, we draw on instrumental variables approach, using physical measures of potential access as well as a break in time that greatly increased the odds of development. Because the data for our endogenous variable is often missing, we are

[1] A similar, but different, measure is provided in 1910, amounting to 304,951 acres

limited to the reduced form. In particular, we conduct a reduced form triple-difference analysis to assess the role of groundwater and surface water access on agricultural development. Because timing and location of actual water development may be related to unobserved county characteristics that are also correlated to agriculture outcomes, we opt to utilize exogenous physical measures to define the potential for increases in surface water and groundwater supplies. Without direct observations of water development, we are precluded from using actual time of development within a county as the time of treatment. Instead, we define a pre- and post-treatment period sometime in between the 1940 and 1950 censuses. Though some Bureau of Reclamation Projects and other efforts had taken place by this time, large reservoir infrastructure took off after this point. Likewise, some groundwater sources had been developed, but post WWII witnessed technological improvements and access to cheaper energy that greatly increased the likelihood of harvesting water from aquifers. By assigning a uniform treatment period, concerns over endogenous timing are also removed, as we again rely on the potential for treatment rather than actual treatment as our identification strategy.

Though we discuss access to groundwater as binary, at the county level we utilize a continuous measure, indicating the percentage of the county over an aquifer. To get the third difference, we then interact these with surface water access, determined by the highest order stream found in the county. Those counties with a stream order of 4 or above (on a scale of 1-7) are considered to have high supplies of surface water. These larger rivers are also most likely to attract a Bureau of Reclamation project.

For each county $i = 1,2, \dots, n$, a proportion of land, A_i, overlies an aquifer. Other fixed properties that could affect the value of land within the county, L_i, are observed.

Land value per acre is observed for each county at time $t = 1,2,\dots,T$, and is represented by Y_{it}. Define the indicator variable I_t^P such that $\mathrm{I}_t^P = 1$ when t>1940. Define the dummy variable I_i^S such that for any county *i* with stream order five or above, $\mathrm{I}_i^S = 1$, and 0 otherwise. The basic triple difference regression is:

$$\log(\mathrm{Y_{it}}) = \alpha + \beta \mathrm{I}_i^S + \delta \mathrm{A}_i + \sigma \mathrm{I}_i^S \cdot \mathrm{I}_t^P + \eta \mathrm{I}_i^S \cdot \mathrm{A}_i + \rho \mathrm{I}_t^P \cdot \mathrm{A}_i + \phi \mathrm{I}_i^S \cdot \mathrm{I}_t^P \cdot \mathrm{A}_i + \gamma_t \mathrm{P}_{it} + \boldsymbol{\lambda_t}' \mathbf{L_i} + \omega_t pop_{\boldsymbol{it}} + \tau_t + \mathrm{u_{it}}$$

where τ_t is the census year fixed-effect. The coefficient β is the differential effect of land value in counties with high surface water through 1940. δ is the relationship between aquifer proportion and land value to 1940 in counties with low surface water availability. σ is the differential land value increase of high surface water counties after 1940. η is the differential effect that high surface water counties have on the relationship between proportion aquifer and high surface water counties up to 1940. ρ is the increase in the relationship between land value and proportion over aquifer after 1940 for low surface water counties. Finally, ϕ is the increase in the relationship between land value and proportion over the aquifer for high surface water counties after 1940.

P_{it} is the average amount of precipitation the county received for the 10 years prior to the relevant census that influences land values and the need for water development. In addition, we include a number of other physical measures that may correlate to our potential access measures and agriculture land values. Included in $\mathbf{L_i}$ are soil quality, elevation, slope mean and range, latitude and longitude, and county size, while we also control for county population ($pop_{\boldsymbol{it}}$), which varies over time. To compensate for a number of variables that do not vary over our long sample, we allow the

estimated coefficients to vary over time instead, allowing soil quality to have a differential impact across censuses. Though county size is not an exogenous physical attribute, we include it because counties tend to be larger where land values are smaller and larger counties are more probable to include a large stream and more likely to have portions not over an aquifer. Last, for our main specification, we also include state fixed effects and weight the regression by farm acreage, as we are interested on the impact on agricultural land.

In addition to looking at land value, we repeat the regression on additional agricultural outcomes. To isolate the impact on revenue from profit, we consider the natural log of the value of crops sold. To assess the extent to which water is used to augment already irrigated land compared to bringing more land under irrigation, we consider the fraction of land irrigated. Last, we look at a number of related structural changes including total farm acreage, the number of farms, and the average farm size. To test the robustness of our results we conduct a number of alternative specifications including altering the sample and controls.

By controlling for τ_t, the time fixed-effect, and υ_i, the county fixed-effect this specification only examines the changes of the period post-1940—all the variation up until 1940 is absorbed into the fixed effects:

$$\log(\mathrm{Y_{it}}) = \alpha + \sigma \mathrm{I}_i^S \cdot \mathrm{I}_t^P + \rho \mathrm{I}_t^P \cdot \mathrm{A}_i + \phi \mathrm{I}_i^S \cdot \mathrm{I}_t^P \cdot \mathrm{A}_i + \upsilon_i + \boldsymbol{\lambda_t}' \mathbf{L_i} + \tau_t + \mathrm{u_{it}}$$

IV. Results

Reported in table 4, regression coefficients indicate no statistical distinction between high-flow counties and low-stream counties, no statistical impact of increasing the fraction of a county above an aquifer, nor the interaction of the two water access

measures prior to 1950 across all outcome variables. After 1950, however, results indicate a number of relative changes. For a county completely overlying an aquifer, farm values (including buildings) increase by 21 percent relative to the overall change. The gains are exclusively garnered by counties without high-flow streams.

Revenues, as measured by crop production per acre, increase substantially (around 73 percent) for counties overlaying an aquifer completely. To a lesser degree, the crop value also increases for counties with high stream flow relative to low-flow counterparts.

One apparent distinction is that aquifer counties substantially increase the fraction of farm acres that are irrigated, by 7 percentage points while high-flow counties increase the fraction by only 1.5 percentage points.

The difference in the evolution could be for a number of reasons. Water from irrigation districts and Bureau of Reclamation projects may be primarily used by acreage already irrigated, providing some increase in crop revenue but at an increased price. Another possibility is that irrigation districts are expanding farm acreage, replicating existing farms but on more marginal land. Given that crop value increases, though, this explanation seems less likely. Furthermore, looking at column 5, there is no evidence that total farm land is being expanded. Therefore, the increase in value of crops is likely smaller than in the aquifer counties because they are providing additional units of water rather than initial units of water, creating a lower marginal productivity of the water. Meanwhile, the increased revenue is not capitalized into the land or buildings, suggesting that the increased revenue is somehow offset. We propose this is due to the increased costs stemming from the reservoir projects. Though these will provide some stability, the gain does not appear to outweigh the costs.

Meanwhile, there is a structural change in the farm economy amongst the counties with aquifers. Over time there are more small farms following the access to groundwater. This suggests that water access is reducing the economic farm size and allowing additional entrants. The same result is not found for counties with high-flow surface access. If we instead consider county level fixed effects, we do see a small expansion in total farmland as well based on access to an aquifer; counties completely over an aquifer increase farm land by 10 percent in aggregate.

V. References

Bretsen, S. N., & Hill, P. J. (2006). Irrigation Institutions in the American West. UCLA J. Envtl. L. & Pol'y, 25, 283.

Clarke, S. H. (1994). Regulation and the revolution in United States farm productivity. Cambridge University Press.

Gardner, B. L. (2009). American agriculture in the twentieth century: How it flourished and what it cost. Harvard University Press.

Haines, Michael R. (2010). Historical, demographic, economic, and social data: The United States, 1790-2002. Ann Arbor, MI: Inter-University Consortium for Political and Social Research. http://doi.org/10.3886/ICPSR02896.v3

Hornbeck, R., & Keskin, P. (2014). The historically evolving impact of the Ogallala aquifer: Agricultural adaptation to groundwater and drought. *American Economic Journal: Applied Economics*, *6*(1), 190-219.

Kitchens, C., & Fishback, P. (2015). Flip the Switch: The Impact of the Rural Electrification Administration 1935–1940. *The Journal of Economic History*, *75*(04), 1161-1195.

Lewis, J., & Severnini, E. (2014). The Value of Rural Electricity: Evidence from the Rollout of the US Power Grid.

Minnesota Population Center. 2006. Historic Counties for the 1910 Census of Population: vector digital data. Minneapolis, Minnesota. http://www.nhgis.org

National Atlas of the United States. 2014. 1:1,000,000-Scale Hydrographic Geodatabase of the United States—Conterminous United States: Vector digital data. Rolla, MO. http://nationalatlas.gov/atlasftp-1m.html

PRISM Climate Group. Oregon State University, http://prism.oregonstate.edu

Rasmussen, W. D. (1962). The impact of technological change on American agriculture, 1862–1962. The Journal of Economic History, 22(04), 578-591.

USDA (2013) Irrigation and Water Use: Background. Online report based on 2007 US Agricultural Census data. Accessed March 31, 2015. URL: http://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/background.aspx

USDA NRCS. 2006. Digital General Soil Map of U.S.: Tabular digital data and vector digital data. Fort Worth, Texas. http://websoilsurvey.nrcs.usda.gov

USGS. (2003). Principal Aquifers of the 48 Conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands: digital data. Reston, Virginia. http://water.usgs.gov/lookup/getspatial?aquifers_us

USGS EROS Data Center. GTOPO30 global digital elevation model: raster data tiles. Sioux Falls, South Dakota. https://lta.cr.usgs.gov/GTOPO30

FIGURES

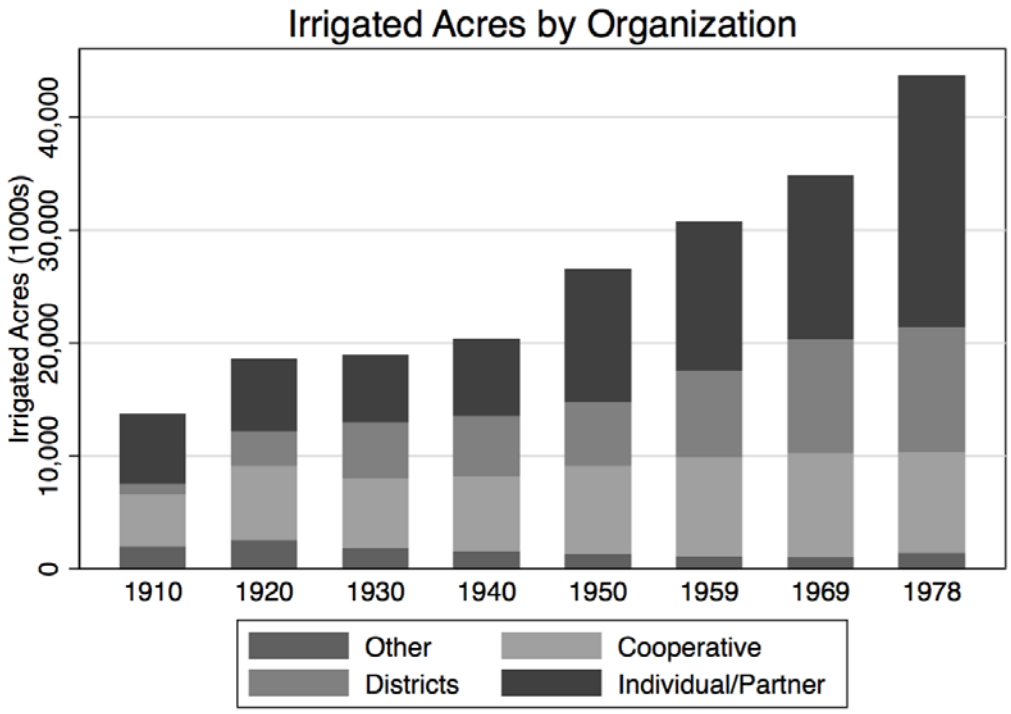


Figure 1. Irrigated acreage in the 17 western states by enterprise type. Data comes from various irrigation and agricultural censes.

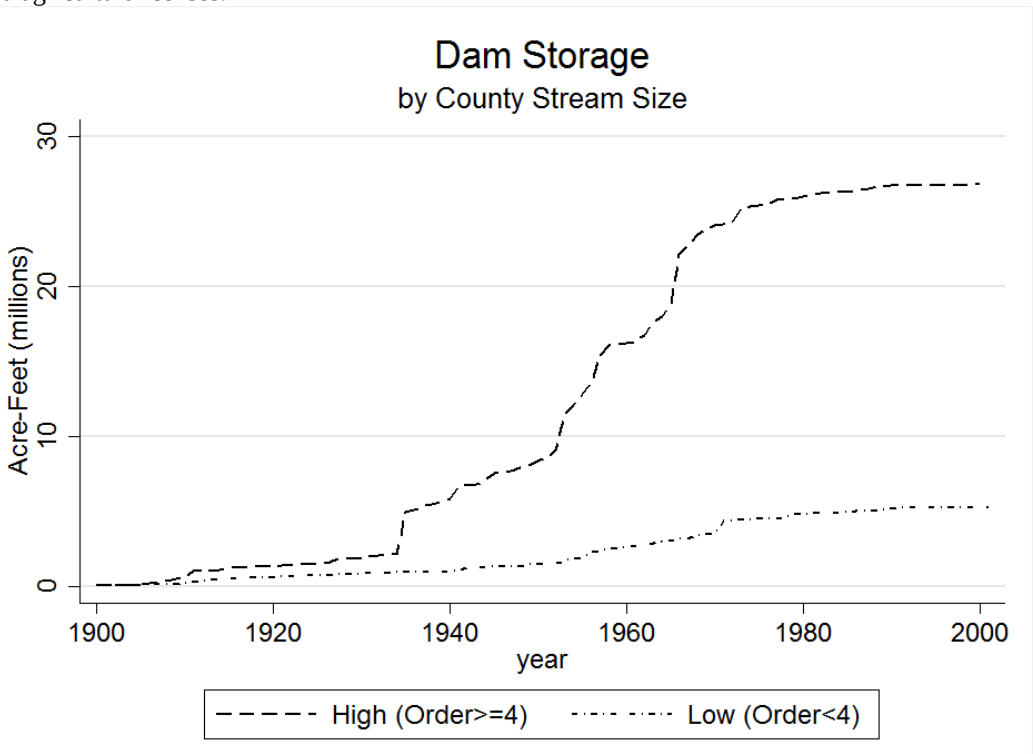


Figure 2. Data from the National Inventory of Dams. Cumulative storage is reported by the highest order stream section in the county. Higher levels are associated with more water.

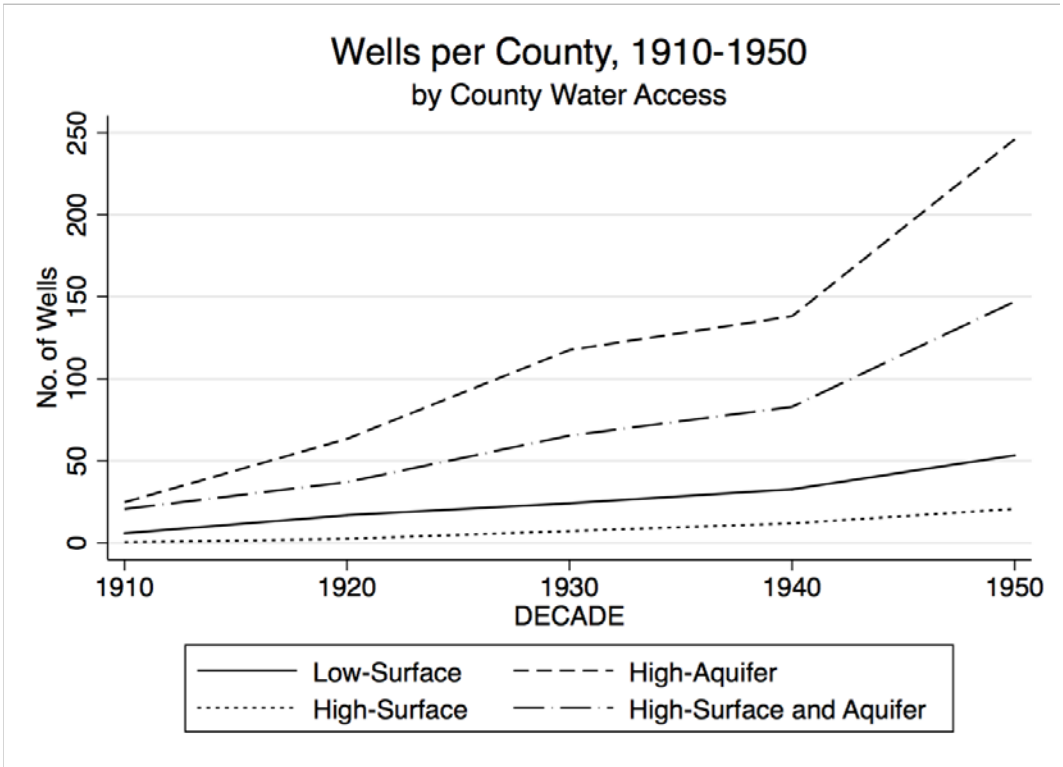


Figure 3. No. of pumping wells for 17 western states. 1910-1940 from Haines et al.; 1950 collected from 1950 irrigation census, county table 2 part 2. For binary aquifer indicator we utilize the 25th percentile cutoff of 0.27 over an aquifer

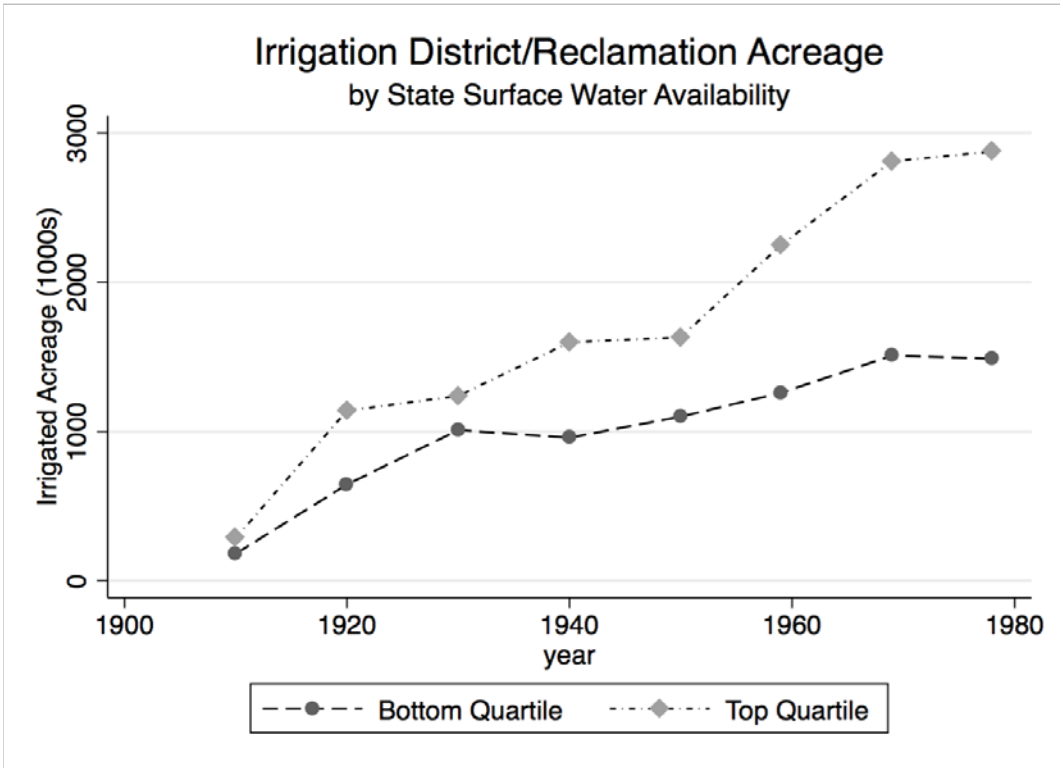


Figure 4: Irrigated acreage under an Irrigation District or the Bureau of Reclamation

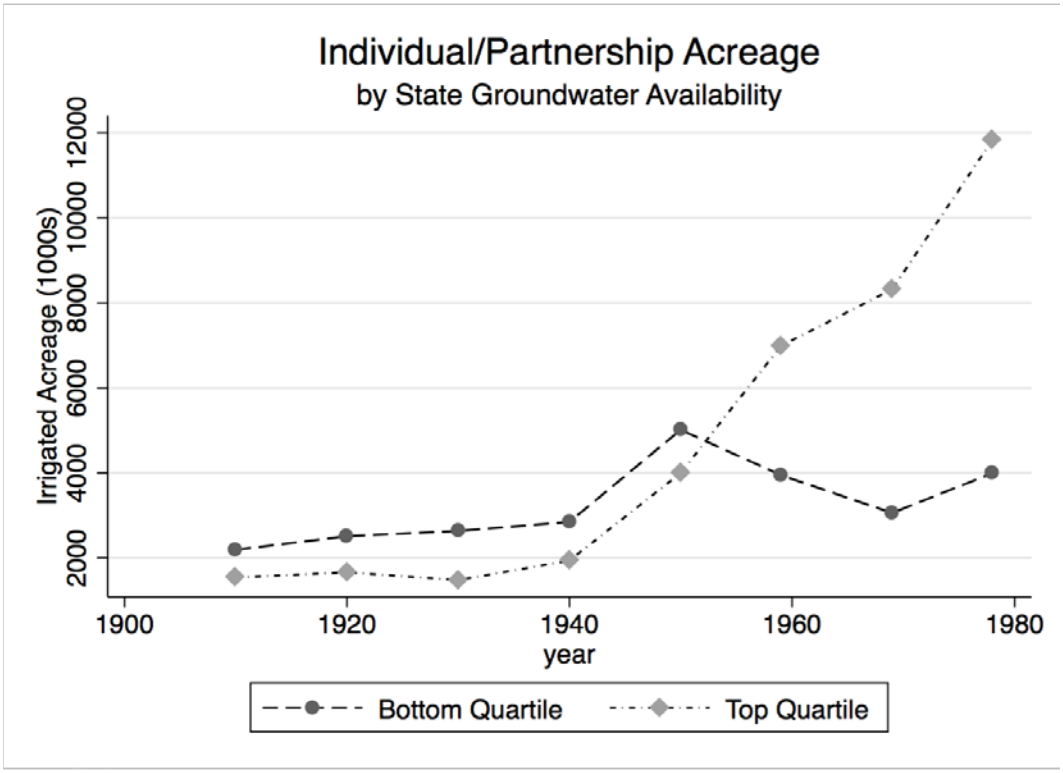


Figure 5: Irrigated acreage under individuals and partnerships

TABLES

Table 1a: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Value per acre (1967$)	6,026	118.72	180.28	0	3,858.43
Value of crops sold per acre (1967$)	5,378	13.96	28.40	0	782.15
Percent acreage irrigated	6,038	0.08	0.14	0	1
# Farms	6,038	1,014.42	1,059.32	0	12,653.00
Total Farmland (acres)	6,038	673,762.40	779,142.30	0	9,053,658.00
Average Farm Acreage	6,034	1,707.04	7,690.92	0	450,000.00
Max Surface Flow	672	3.94	1.38	1	7
Surface Indicator (Order>3)	673	0.60	0.49	0	1
Fraction over aquifer	673	0.59	0.37	0	1
Surface Indicator x Fraction over aquifer	673	0.35	0.40	0	1

Note: Observations for all counties west of the 98th Meridian. Census data from 1900, 1910, 1920, 1930, 1940, 1950, 1959, 1969, 1978 reports, except crop value is unavailable in 1900

Table 1b: Summary Statistics by Period and Water Access

Variable	Obs	Mean	Obs	Mean	Difference in Mean
By Time Period					
	Pre-1950		Post-1950		
Value per acre (1967$)	3,339	84.75	2,687	160.94	76.19***
Value of crops sold per acre (1967$)	2,691	12.82	2,687	15.10	2.28***
Percent acreage irrigated	3,346	0.08	2,692	0.08	0.00
# Farms	3,346	1,146.08	2,692	850.78	-295.31***
Total Farmland (acres)	3,346	535,215.90	2,692	845,967.60	310,751.7***
Average Farm Acreage	3,344	1,502.75	2,690	1,961.00	458.25**
By Surface Access pre 1950					
	Max Order <4		Max Order>3		
Value per acre (1967$)	1,346	82.28	1,993	86.41	4.13
Value of crops sold per acre (1967$)	1,079	11.72	1,612	13.56	1.85**
Percent acreage irrigated	1,352	0.06	1,994	0.09	0.04***
# Farms	1,352	979.81	1,994	1,258.82	279.01***
Total Farmland (acres)	1,352	440,642.50	1,994	599,339.80	158,697.3***
Average Farm Acreage	1,350	1,963.24	1,994	1,190.98	-772.26**
Max Surface Flow	1,352	2.61	1,989	4.85	2.24***
Fraction over aquifer	1,352	0.59	1,994	0.59	0.00
By Aquifer Access pre 1950					
	Aquifer<0.27		Aquifer>0.27		
Value per acre (1967$)	837	73.73	2,502	88.43	14.70***
Value of crops sold per acre (1967$)	681	10.63	2,010	13.57	2.93***
Percent acreage irrigated	839	0.07	2,507	0.08	0.01**
# Farms	839	1,083.58	2,507	1,167.00	83.43**
Total Farmland (acres)	839	496,550.80	2,507	548,155.60	51,604.80**
Average Farm Acreage	839	717.80	2,505	1,765.66	1047.86***
Max Surface Flow	839	3.91	2,502	3.96	0.05
Fraction over aquifer	839	0.08	2,507	0.76	0.68***

Table 2: Variable Descriptions

Variable	Description	Source
Latitude and longitude	At centroid of county shapefile, in decimal degrees	Minnesota Population Center 2006
Area	Of 1910 county shapes, in acres	Minnesota Population Center 2006
Elevation	Average elevation of county shape, in meters	USGS EROS Data Center
Soil quality (irrigated)	Irrigated capability class, 1-high to 7-low (muaggatt: iccdcd)	USDA NRCS 2006
Soil quality (non-irrigated)	Non-irrigated capability class, 1-high to 8-low (muaggatt: niccdcd)	USDA NRCS 2006
Mean slope	Soil slope gradient, percent (muaggatt: slopegraddcp)	USDA NRCS 2006
Range slope	Range of slope gradient (muaggatt: slopegraddcp)	USDA NRCS 2006
Surface water availability	Highest Stahler Order stream in a county, 1-low to 7-high	National Atlas of the US 2014
Groundwater availability	Percentage of county overlying aquifer shape	USGS 2003
Precipitation data		PRISM Climate Group
Total value per Acre		US Ag Census/Haines 2010
Crop value per Acre		US Ag Census/Haines 2010
Average farm size	County average farm size in acres	US Ag Census/Haines 2010
Fraction acres irrigated	Irrigated acres divided by total farm acres	US Ag Census /Haines 2010
Total county population		US Ag Census/Haines 2010

Table 4: Main Regression Results

VARIABLES	(1) ln(Total Value per Acre)	(2) ln(Crop Value per Acre)	(3) Fraction of Acres Irrigated	(4) ln(#Farms)	(5) ln(Farm Acres)	(6) ln(Average Farm Acres)
All						
High Surface	0.133	0.0593	0.00353	0.0690	0.0782	0.00922
	(0.0834)	(0.185)	(0.0112)	(0.101)	(0.0781)	(0.116)
Fraction over an aquifer	-0.00228	-0.236	-0.0122	-0.138	-0.0129	0.125
	(0.0931)	(0.238)	(0.0116)	(0.124)	(0.0933)	(0.130)
High Surface x Fraction over Aquifer	-0.116	-0.0141	0.0212	0.107	0.0912	-0.0159
	(0.106)	(0.275)	(0.0141)	(0.151)	(0.121)	(0.171)
High Surface x Post 1940	0.0512	0.436**	0.0145*	0.0741	-0.0298	-0.104
	(0.0540)	(0.189)	(0.00818)	(0.0727)	(0.0532)	(0.0927)
Fraction over an aquifer x Post 1940	0.211***	1.078***	0.0703***	0.292***	0.0179	-0.274**
	(0.0755)	(0.215)	(0.0127)	(0.101)	(0.0652)	(0.138)
High Surface x Fraction over Aquifer x Post 1940	-0.224**	-0.902***	-0.0522***	-0.145	0.104	0.249
	(0.0961)	(0.325)	(0.0140)	(0.132)	(0.0816)	(0.173)
Observations	6,025	5,354	6,026	6,026	6,026	6,026
R-squared	0.743	0.537	0.436	0.577	0.717	0.675
County Fixed Effects						
High Surface x Post 1940	0.00722	0.342*	0.0113	0.0953	0.0223	-0.0729
	(0.0438)	(0.177)	(0.00852)	(0.0583)	(0.0428)	(0.0792)
Fraction over an aquifer x Post 1940	0.221***	1.003***	0.0711***	0.371***	0.104**	-0.268**
	(0.0515)	(0.185)	(0.0132)	(0.0841)	(0.0485)	(0.108)
High Surface x Fraction over Aquifer x Post 1940	-0.186***	-0.777***	-0.0528***	-0.245**	0.0258	0.271*
	(0.0708)	(0.294)	(0.0149)	(0.105)	(0.0631)	(0.138)
Observations	6,025	5,354	6,026	6,026	6,026	6,026
R-squared	0.929	0.882	0.814	0.920	0.942	0.922

Note: Regressions are weighted by farmland in the county. Additional but unreported controls are year fixed effects, state fixed effects, 10-year average precipitation, soil quality, elevation, slope mean and range, latitude, longitude, total county acreage, and total population. Robust standard errors clustered by county in parentheses

*** p<0.01, ** p<0.05, * p<0.1