Spatiotemporal Patterns of Irrigation Adoption in Alabama

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Introduction

Agricultural communities in Alabama are experiencing some of the nation’s highest, and most rapidly increasing, rates of poverty and economic inequality. As agriculture plays a significant role in the statewide economy, one way to address this widespread disadvantage is through increased farmland productivity. The transition from rain-fed to irrigation-fed (RF to IF) agricultural practices has been shown to significantly increase crop productivity and farm profitability (Salati et al. 2008). Despite the potential to encourage resilience and resiliency in rural economies, irrigated cropland accounts for only 5% of the state’s total cropland as numerous barriers remain to irrigation adoption in Alabama. Despite ample annual rainfall, periodic seasonal droughts can create water restrictions, especially in Alabama’s semi-arid southeast. To date, irrigation expansion policies and initiatives have relied on cross-sectional and spatially coarse analyses, thus masking the fine-granule individual farmer decisions to adopt irrigation. A more holistic approach to improving irrigation policy and practices requires identifying challenges faced by individual farms and communities. This project presents a multi-level mixed effects survival analysis to identify the physiographic, socioeconomic, and economic factors that influence farmers’ receptiveness to the RF to IF transition. We use individual farms as the unit of analysis and integrate spatiotemporal cropland and climatological data with field observations of current irrigation systems and farm-level data including surface water access and average well depth. The results identify the degree to which specific farm attributes influence the timing and location of irrigation adoption and highlight the movements needed to spur the RF to IF transition in Alabama.

Study Area

Alabama is at the intersection of dual challenges of adapting to climate change and growing rural poverty and inequality. Increasing agricultural productivity through adoption of irrigation can address both challenges, yet efforts to expand irrigation in Alabama have had little success. In lands regions such as the Southeast, perceptions of water abundance among farmers and/or policy-makers can hinder irrigation expansion. Despite abundant annual rainfall, however, statewide precipitation is becoming more seasonal, with heavier rainfall in the winter and spring and increasing by periods during the end of the growing season. Alabama is a riparian rights state, which limits water access to properties adjacent to water bodies. From a management perspective, Alabama’s rural developed water use monitoring program consistently estimates and inaccurately reporting from irrigation users. Furthermore, there is no centralized source for disseminating reliable information on potential irrigation strategies or the profitability of long-term irrigation investments in equipment and operating costs. This project is linking farm-level attributes to irrigation adoption decisions and exploring the how broader social influences shape impacts of irrigation adoption in Alabama.

Data

The dependent variable is the time to irrigation adoption, identified using the locations of 1,011 center pivot polygons installed between 2006-2013, determined using USGS 2010 Alabama reality panels from Landgrid and the 2013 NACGD classification for cropland usage, resulting in 32,044 farms with irrigation potential. Access to information was operationalized as the distance from each farm to the nearest Alabama Farmers’ Cooperative location. To incorporate social influence among farmers with access to similar resources, ‘Social Neighborhoods’ were generated around each of the co-locations using Thesaurus polygons.

Table 1: Data Sources

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Independent Variables</td>
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<td></td>
<td></td>
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<tr>
<td>Riparian Rights</td>
<td>Presence of perennial stream</td>
<td>Vector</td>
<td>Geological Society of Alabama</td>
</tr>
<tr>
<td>Water Surface Access</td>
<td>Presence of Lake/Pond</td>
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</tr>
<tr>
<td>Soil Type</td>
<td>Available soil types</td>
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<td>Salati et al. 2008</td>
</tr>
<tr>
<td>Land Use Intensity</td>
<td>Available land use intensity</td>
<td>Vector</td>
<td>Salati et al. 2008</td>
</tr>
<tr>
<td>Groundwater Contaminants</td>
<td>Interpolated well depth</td>
<td>Depth</td>
<td>Geological Society of Alabama</td>
</tr>
<tr>
<td>Information Access</td>
<td>Distance to Cooperative/Extension</td>
<td>Pixels</td>
<td>Alabama Farmers Cooperative, Alabama Extension</td>
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<tr>
<td>Dynamic Independent Variables</td>
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<td></td>
<td></td>
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<tr>
<td>Crop types</td>
<td>Global commodity, normalized by market index</td>
<td>Index</td>
<td>Monthly, Verburg (2011)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Distribution from long-term average precipitation</td>
<td>Index</td>
<td>PRISM</td>
</tr>
<tr>
<td>Social Influence</td>
<td>Irrigated Areas in Social Neighborhood</td>
<td>Pixels</td>
<td>Alabama Farmers Cooperative, Alabama Extension</td>
</tr>
</tbody>
</table>

Survival Analysis

This study investigates the contextual and dynamics factors that have shaped spatiotemporal patterns of center pivot irrigation adoption throughout the state of Alabama. Data for the locations of center pivot irrigation was available for 5 years from 2006-2015. Since the annual time to an irrigation an adoption is unknown for much of the sample, methods such as linear regression would underestimate the duration of unaffected subjects. Survival analysis is a set of time-to-event models that can accommodate right-censored data to reveal the degree to which the effects of covariates influences the probability of a competing event. This project uses survival analysis to analyze the causal effects of farm-level and regional factors on the timing of irrigation adoption. Specifically, we test the following hypotheses:

- Hypothesis Social influences, including the prevalence of nearby irrigated farms, is a stronger predictor of the timing and location of irrigation expansion in Alabama than biophysical factors.
- Hypothesis Economic factors, including initial investment costs and commodity prices are a stronger influence on the timing and location of irrigation expansion than biophysical factors.

Survival Function – Kaplan-Meier Estimation

Formula 1 shows the Kaplan-Meier estimator of the Survival Function where \( t_{k} \) is the number of farms at risk of irrigation adoption up until time \( t \) and \( d_{k} \) is the number of adoption decisions at time \( t \). The plot of the Kaplan-Meier estimator is shown in Figure 2a, where survival probability is the likelihood that a farm will remain unirrigated through each time period. To understand the influence of water access on survival times, conditional Kaplan-Meier estimators were plotted for irrigation practices and the presence of surface water (Figure 2b). As expected, the survival probabilities are higher for farms without access to surface water or irrigation rights.

Formula 2 shows the Nelson-Aalen estimation of the Cumulative Hazard Function where \( t_{k} \) is the number of farms at risk of irrigation adoption at time \( t \) and \( d_{k} \) is the number of adoption decisions at time \( t \). Figure 3 shows the survival function, & its log-log plots commonly used in traditional survival analysis. The Nelson-Aalen estimation of the cumulative hazard rate is used to approximate the baseline hazard function, the survival function, and less directly, the cumulative distribution function (Figure 3).

Results & Discussion

Cox’s Time-Varying Proportional Hazard Model

Dynamic covariates were introduced into the survival analysis using the Cox’s Time-Varying Proportional Hazard Model (Formula 3) in the lifelines Python module and was executed in ArcGIS Pro 2.7. Cox’s Proportional hazards models represent the hazard rate \( h(t|x) \) as a function of time \( t \). The baseline hazard \( h_{0}(t) \) functions similar to an exponential regression models and describes the cumulative hazard rate for \( x \). The log hazard rate of subjects is a function of time-varying covariates \( z \). The hazard ratio is represented by \( \exp(z) \) and indicates the effect of a covariate on survival time.

Future Research

Other forms of irrigation such as drip or micro-irrigation, that we did not consider, may be more feasible for smaller and/or disadvantaged farms. Similarly, due to the focus on center pivot irrigation, these results are most applicable to center pivot operations and not for other forms of irrigation such as pivot irrigation, where high value produces for direct sale (e.g., farmers’ markets). Future research will include higher-level, regional modeling of the impact of the study results on demographic status of farmers throughout the region and will shed light on motivations for crop choices and irrigation practices. Moreover, the analysis shown here warrants further investigation into the possible ways to incorporate conceptual variables, particularly social influence. Social interactions may be better represented by a network structure, rather than a spatial neighborhood or proximity to the neighborhood center. An analysis that implements social influence for global environmental change studies.

References

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8. PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 3 Feb 2004