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Evaluation of Factors Influencing Irrigation Adoption Among Farmers in the Southeast

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EVALUATION OF FACTORS INFLUENCING IRRIGATION ADOPTION AMONG FARMERS IN THE SOUTHEAST

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In Partial Fulfillment
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by
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ABSTRACT

Irrigation adoption can improve the yield and frequency of use of crop land, therefore increasing the quality and output of irrigated farms. With the expectation of water shortages out West, as well as an increasing population in the U.S., there is a greater opportunity for farmers in the Southeast to supply agricultural products, such as food and fiber. The proportion of farmers who irrigate, the proportion of farmland that is irrigated, and irrigated land's share of the area of farms that irrigate in Alabama, Florida, Georgia, North Carolina, South Carolina, and the five-state region of the Southeast are used to describe the trends from 1997-2017. Additionally, I use a fixed effect logistic model to estimate the effects of demographic and economic variables that might influence the proportion of a county's farmers who irrigate. All state and county data used in the descriptive and analytical sections were obtained from the United States Department of Agriculture, published in the respective year's Census of Agriculture. Irrigation in the Southeast increased from 2012 to 2017 for all three proportions used. Further, in the county-level logistic model, the proportion of female farmers, the proportion of farmers whose primary occupation is not farming, the proportion of farmers over the age of 65, and the average farm's dollar value of machinery assets all significantly affect the proportion of farmers who irrigate.

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INTRODUCTION

Irrigation in the southeastern United States, defined as Alabama, Florida, Georgia, North Carolina, and South Carolina, has increased at a dramatic rate from 1962-2012 (Templeton et al, 2017), but the question remains why, and whether this trend continues for 2012-2017. Through this paper I attempt to answer these questions by expanding on the descriptive results found in previous studies to more years, as well as using an expanded data set to examine the influence of certain demographic and economic variables on the probability of a farmer to irrigate (Templeton et. al, 2017; Jackson, 2013).

Agricultural irrigation can be very beneficial, yet the cost of irrigation can be substantial to both society and the individual farmer. However, the irrigation efficiency, or “share of applied water that is beneficially used by the crop” has increased through improvements in irrigation systems, leading to savings in water costs (USDA, 2019). Agricultural irrigation is used for seedbed preparation, germination, root growth, plant growth, yield, and quality (DJPR, 2018), and can lead to much more frequent use of crop land for production, allowing farmers to produce more product than naturally allowable. Further, it can be used as an insurance proxy to allow the farmer to hedge the risk to their crops from environmental instability (MSU, n.d.). Competition for water resources in the West (Perrone, Murphy, Hornberger, 2011) could lead to further decreases in western irrigation and agricultural production, and the opportunity for greater importance placed on agriculture in the Southeast (Knox, Fuhrmann, and Konrad, 2014; Jackson, 2013). This is due to the fact that the decision of a farmer to irrigate is “dependent on the availability of water in terms of adequacy, timeliness, and equitability" (Adekunle, Oladipo, and Busari, 2015).

If this is true, the question arises as to why we see discrepancies of irrigation between similar farmers in the same region. With the advancement of many tools and practices that improve agricultural productivity, there is a need for demographic and economic data to understand the driving forces more accurately. Studies have been conducted, focusing on using these variables to describe farmers' actions, but an updated, separate, and individual study done of the Southeast is necessary.

I focus only on the Southeast region and certain demographic and economic variables of the representative farmer. My description and analysis do not pertain to policy debates or the amount of irrigation water applied. Furthermore, I ignore the different methods and systems of irrigation, such as gravity or pressure-sprinkler systems (Hogan et. al, 2007). The on-farm efficiency of irrigation methods and systems varies, and the degree of efficiency depends on the region (USDA, 2019). The estimated coefficients on variables in my logistic model are not estimated effects or estimates of causation. Rather, in the model I identify the variables that are significantly correlated with the proportion of farmers who irrigate.

LITERATURE REVIEW

There has been a growing trend within the last two decades to begin studying the influence of economic and demographic variables on irrigation adoption. One such studywas done by Pokhrel, Paudel, and Segarra (2018), which produced a Poisson model to estimate the impact of certain demographic variables on the probability of irrigation adoption among cotton farmers in the United States. Some of the independent variables controlled for are age (measured in years), land holding size (measured in acres), regional dummies, and proportion of income from agriculture. The authors found age and landholding to not be significant at the 5% level but did find the regional indicator of Texas and Oklahoma to be significant at the 1% level. The significance of the location indicator shows that irrigation adoption is dependent upon the region, with the fixed effects accounting for a very large portion of the decision of a farmer to invest in irrigation adoption. This is validated by a study whose authors examined the influence of water costs on irrigation adoption in Georgia (Alvarez, Keeler, and Mullen, 2006). Alvarez et. al produced a model controlling for variables such as pumping costs ($ per acre foot), the Blaney-Criddle index of crop water requirement, and the type of crop, and found that all variables were statistically significant. Since water costs vary by region (Alvarez, Keeler, and Mullen, 2006), there is a need to either directly control for water costs and these other variables or indirectly control for them with dichotomous indicators of counties.

In the Pokhrel, Paudel, and Segarra (2018) study, the proportion of income from farming was found to be not a significant factor in irrigation adoption, which is a direct contradiction to the findings of Molnar et. al (2011). Molnar et. al separated their study variables up into perception and characteristic variables, controlling for such effects as age, gender, farm size, reliable source of water, and proportion of income from agriculture. After running two regressions, one using only characteristic variables such as age and gender, and the other using both perception and characteristic variables, the authors found that the proportion of income from farming was significant at the 1% level. However, both groups found age and landholding to not be significant. The literature regarding the influence of age on irrigation adoption is very diverse, with some authors finding age to be significant (Chuchird, Sasaki, & Abe, 2017; Koundouri, Nauges, and Tzouvelekas, 2006).

Adeoti's (2009) paper looks at some of the same socioeconomic variables discussed in the other papers, using a sample of farmers in Ghana. Some of the variables the author controls for are the age of the head of household, proportion of head of households that are male, and credit access. Access to credit was a binary variable that included formal and informal sources of credit as 1 and other as 0. Adeoti estimated five variables to be significant at the 10% level, with access to credit being one of them. This emphasizes the fact that some farmers, who want to irrigate, may be unable to, potentially leading to less than ideal outcomes.

METHODOLOGY

Description of Irrigation Trends in the Southeast

The data used for the descriptive statistics in this study were gathered from the Census of Agriculture for the years 1997, 2002, 2007, 2012, and 2017, with the 2017 Census being an expansion upon the years and proportions calculated in previous studies. The proportions and variables were the same as those used by Templeton et. al (2017), and Jackson (2013), therefore the methodology and pre-2017 results are similar. There are five variables used in order to determine three different proportions. However, how irrigation adoption is defined changes between the proportions, based on the units of measure. These proportions are used in order to determine and visualize certain time trends across all five states, and the Southeast as a whole. The five variables used in the descriptive proportions are irrigated acres, total agricultural land, total agricultural land with any irrigation, farm operations with any irrigation, and total farm operations.

The Census of Agriculture includes all farms that sell, or would have sold, $1,000 or more of fruit, vegetables, or some food animals throughout the year, and is taken once every five years (NASS, 2019). The reason that I used state level data when calculating the descriptive statistics, even though the data at the county level is fully adjusted for "undercoverage, nonresponse, and misclassification" as possible (NASS 2019, Appendix A, p. A-9), is that some of the data were withheld due to disclosure reasons. By using state level data, the trends should portray a more accurate representation of the true population, and counties with few farms will still be accounted for.

The first proportion calculated is the proportion of irrigated acres in a state to the total agricultural land in that state. Irrigated land is defined as "all land watered by any artificial or controlled means" and each acre is only accounted for once in the census, regardless of the amount of times irrigated (NASS 2019, Appendix B, p. B-12&13). Total agricultural land is labeled as "Land in farms" by the surveyors and primarily accounts for all land used for crops, pasture, and grazing (NASS 2019, Appendix B, p. B-13). Further, acreage that "includes woodland and wasteland not actually under cultivation or used for pasture or grazing" is included in the variable but "woodland or wasteland held for nonagricultural purposes" is deleted (NASS 2019, Appendix B, p. B-13). This proportion is presented in table 1 and illustrated in figure 1.

The second descriptive proportion calculated is the ratio of farm operations that irrigate to total farm operations. Farm operations that irrigate is defined as the number of farms in a state that have irrigation present on the operation. As mentioned above, a farm operation is only counted as long as it produced and sold, or normally would have sold, more than $1,000 of agricultural products (NASS 2019, Appendix A, p. A-1). Total farm operations are the aggregate of all farm operations in each individual state. This proportion is presented in table 2 and illustrated in figure 2.

The third, and last, proportion calculated is the ratio of irrigated acres to total agricultural land with irrigation present on the operation. The numerator variable is the same as in the first equation, and accounts for the total number of acres irrigated in a state. The denominator variable is the number of acres in a state when only accounting for farms that have any form of irrigation present on their farm. By excluding farmland that has no irrigation on the operation, the proportion only includes farmers that irrigate. When comparing and contrasting individual states we can see the difference in the proportions given that the farmer irrigates. This proportion is presented in table 3 and illustrated in figure 3.

Analysis of the Incidence of Irrigation during 1997-2017 in Five Southeastern States

The data used for the analysis of the county-level proportions were all gathered from the county and state level dataset in the Census of Agriculture, and includes the years 1997, 2002, 2007, 2012, and 2017. The variables included in the regression equations are similar to a previous paper from Jackson (2013), therefore the methodology is similar. However, a unique asset variable was included, and the race and internet variables were removed due to data limitations.

The theory behind a farmer's adoption of irrigation, using the net present value model, is that a farmer will not invest in irrigation until the expected present value of the investment equals the cost of the investment (Carey, Zilberman, 2002). Therefore, we act under the assumption that a farmer will irrigate only if it is profitable for him to do so (Jackson, 2013).

The dependent variable used in the regression equation is the log odds of a farm irrigating. The dependent variable is different than the proportion calculated in table 2 due to county level values being used in the model, and state level values being used in the descriptive trends. To take the log odds, first the proportion of the event happening must be calculated. Next, the proportion calculated is divided by one minus the same proportion, resulting in the odds. The natural log of the odds is the log-odds, which is the dependent variable regressed. Therefore, the coefficient estimated in the logistic regression is "the estimated increase in the log odds of the outcome per unit increase in the value of the exposure" (Szumilas, 2010). The reason behind taking the log odds, instead of running the simple xtlogit command, is that our dependent variable is in the form of a proportion, instead of binary.

The independent variable, average farm size of a county, is calculated by taking the total farm land and dividing it by total number of farm operations in that county. Total farm land and total number of farm operations are the same variables used in the descriptive proportions, just gathered at the county level. Average farm size has the units of measure of acres per farm.

Machinery assets per acre is another independent variable. The machinery assets per acre is the total dollar value average of machinery assets in a county divided by the total agricultural land in that county. Machinery is only counted if it is located on, or normally located on, the operation and not obsolete or abandoned (NASS 2019, Appendix B, p. B-54). Further, machinery and equipment are defined as trucks, tractors (excluding garden tractors), grain and bean combines, cotton pickers and strippers, forage harvesters, and hay balers (NASS 2019, Appendix B, p. B-47). Since machinery assets per acre is the only variable with a unit of measure in currency, it is the only variable that had to be adjusted for inflation (BEA, 2019). To do this, the BEA deflator used had a base year of 2012, and adjusted 1997-2012 dollars to 2017-dollar values. Machinery assets and land assets are both used when banks determine credit rates.

Whether a farmer's primarily occupation is farming is the next independent variable controlled for in the logistic regression. To calculate this variable the number of principal farmers whose occupation is primarily not farming in a county is divided by the total number of farmers in a county. However, for the year 2017 the county level values were missing, therefore the state level proportions were imputed into each county within that state. For the years 1997-2012 a principal farmer is defined as a "person primarily responsible for the on-site, day-to-day operation of the farm or ranch business" (NASS 2014, Appendix B, p. B-19). In 2017 NASS changed the terminology from primary operator to primary producer, and only accounted for primary producer's occupations including and excluding farming at the state level (NASS 2019, Appendix B, p. B-20).

The independent variable for gender is the proportion that a farmer is female in a given county. As with the occupation variable, due to data constraints, the proportion that a farmer is female for the year 2017 is the state proportion imputed into each county. The last demographic independent variable calculated is the proportion that a principal farmer was over the age of 65 for a given county. People older than 65 are generally more conservative in terms of investment (Mata et. al, 2012), therefore the expectation would be that the older the person, the less likely they are to irrigate. Once again, the data for the year 2017 were taken from the state level and imputed into each individual county due to data constraints.

To determine the effects of each independent variable on the probability of a farm irrigating, a fixed effects logistic regression model is used for all five individual states as well as the whole Southeast region. The reason for including all six regressions is that there is the possibility that the coefficients of the variables differ between states, allowing the estimated coefficients to have different results dependent upon the state and region. For purposes of this paper year indicator variables were included, with 1997 as our base year.

Since time invariant variables such as soil composition and the proportion of a county's population that is of different races is not controlled for in the model, a fixed effects model would be needed (Williams, 2018). When implicitly controlling for the individual counties the model is encapsulating all omitted effects into the individual county, producing more accurate estimates. The importance of controlling for these variables cannot be understated due to the potentially large, and relatively unknown, influence they have on irrigation adoption. Further, a regression is ran including only data from each individual state, and then data from all five states. We would expect there to be differences in the estimates between states such as Florida and Georgia due to crop diseases such as citrus greening that are only present in Florida. Therefore, my econometric model is defined as

$$LOIRRPROP = \beta_0 + \beta_1 FARMSIZE + \beta_2 MASSETPACRE + \beta_3 WORKNOTFARM + \beta_4 FEMALE + \beta_5 OLD + \in$$

RESULTS

Description of Irrigation Trends in the Southeast

The ratio of irrigated acres to total agricultural land increased, on average, for all states in the Southeast, except for North Carolina and Florida from 1997-2017 (Table 1). However, Florida has the highest share of irrigated acres when compared to the other four states and maintained relatively similar shares during 2012-2017 (Table 1). North Carolina increased its share from 1997-2002 but then went on a constant downward trend from 2002-2017, with Alabama and South Carolina increasing or remaining constant throughout the 20-year span (Table 1). The Southeast region maintained constant increases in its share of irrigated acreage of total farmland, except between the years 2002-2007 (Table 1).

Florida's proportion of farms that irrigate (Table 2) decreased much more significantly than its proportion of irrigated acreage of all farmland (Table 1), going from roughly 30% of farms irrigating to under 25% within the 20-year span. Georgia's proportion of farms that irrigate increased substantially during 2012-2017, even though the share of farms irrigating seemed to be leveling off from 2007-2012 it increased from 12.38% to 14.59% between 2012-2017 (Table 2). South Carolina's proportion of farms that irrigate followed a similar trend as Georgia's proportion of farms irrigating, staying approximately constant between 2002-2012, and then increasing its proportion of farms irrigation from 2012-2017 (Table 2). The proportion of farms that irrigate in the Southeast region is relatively constant, increasing from 1997-2002 and 2012-2017, but decreasing from 2002-2007 and 2007-2012.

The share of irrigated acres in a farm that has any irrigation fluctuates more than the share of farms that irrigate and the share of irrigated acreage of total farmland (Table 3), with multiple states seeing increases and decreases throughout the 20-year span. Alabama and North Carolina maintained relatively similar shares of irrigated acres on farms that irrigate across the 20-year period, with North Carolina having a slightly higher percentage of irrigated acres in 2017 than 1997 (Table 3). Georgia and South Carolina maintained their trend of increasing their share of irrigated acres throughout the 20-year span, except in South Carolina from 1997-2002 (Table 3). Florida decreased its share of irrigated acres on farms that irrigate from 1997-2012 but increased from 2012-2017 (Table 3). Overall Florida decreased its share from 0.40903 to 0.37760. The Southeast region's trend is similarly sporadic, with the share of irrigated acres on farms that irrigate decreasing between 1997-2002 and increasing from 2007-2017 (Table 3).

The trends in all three tables were relatively consistent, however the proportion of irrigated acreage on farms that irrigate (Table 3) is much larger than the proportion of irrigated acres of total farmland (Table 1). In terms of share percentages Florida is an outlier, irrigating at a much higher proportion than the other four states, regardless of the unit of measure. Georgia is beginning to have similar proportions of irrigated acreage of total farmland (Table 1) and irrigated acreage of farmland on a farm that irrigates (Table 3) in comparison to Florida. Inversely, Alabama is an outlier irrigating at a much lower rate, except when using only acres of farms with irrigation present (Table 3). Overall, the 1997-2012 trends continued when accounting for the 2017 Census except for the share of farmers that irrigate in Alabama (Table 1) and the share of irrigated acreage on farms that irrigate in Florida (Table 3).

Analysis of the Incidence of Irrigation during 1997-2017 in Five Southeastern States

When estimating the logistic regression, in regard to Alabama, average farm size, machinery assets per acre, and the 2007-year indicator are all statistically significant at the 5% level. The proportion of farmers that are female and the proportion of farmers over the age of 65 have relatively large negative coefficients, however due to the large standard errors are not significant. Even though average farm size and machinery assets per acre are significant, they only increase the log odds of a farmer irrigating by .002 and .0009 respectively.

There were zero significant independent variables estimated in Florida's state regression at the 5% level, and only the proportion of farmers over 65 is significant at the 10% level. However, every year indicator, except for 2002, is negative and statistically significant. The 2017-year indicator has the largest estimated coefficient out of 2002-2017, with the odds of a farmer irrigating in 2017 being .6621 when compared to 1997. Out of all of the individual state regressions, Florida is the only state that has a positive coefficient associated with the proportion of female farmers, and one of two that has a positive coefficient associated with the proportion of farmers over 65 years of age.

Based on the descriptive results there is reason to compare and contrasts the states of Georgia and South Carolina, due to both increasing irrigation adoption at a substantial rate over the 20-year period. The independent variables of average farm size and proportion of farmers who are primarily occupied as nonfarmers are all statistically significant at the 1% level in Georgia. In Georgia, if the proportion of farmers whose primary occupation is actually not farming increases one percentage point, the proportion of farmers who irrigate decreases 10.45 percentage points (Table 6). It is safe to conclude that the variables proportion of farmers who are not primarily occupied as farmers and farm size are both correlated with whether a farmer irrigates in Georgia. South Carolina had zero significant variables, but all four-year indicators were significant at the 1% level. Further, the proportion of female farmers is significant at the 10% level for South Carolina, but not Georgia. North Carolina's only significant variable, excluding year indicators, is the proportion of farmers who are not primarily occupied as farmers. This coefficient had the largest correlation with whether a farmer irrigated in North Carolina.

After conducting a Hausman test on the regional level regression we reject the null hypothesis, therefore validating our need to use a fixed effects model. Comparing the results at a regional level there is the immediate observation that four out of five independent variables are significant at the 5% level, with machinery assets per acre being the variable excluded. This is reinforced by the state results, with machinery assets per acre being significant only for Alabama. Therefore, we cannot conclude that there is an effect of machinery assets per acre on the probability of a farmer irrigating in the Southeast region. The main difference between the individual state results and the regional result is the magnitude of the standard error. All six regressions have a positive relationship between the probability of a farmer adopting irrigation and farm size. A one-hundred acre increase in farm size leads to an increase of 0.01 in the probability that a farmer irrigates, or an increase of one percentage point in the proportion of farmers who irrigate in the Southeast (Table 6)

DISCUSSION OF RESULTS

Description of Irrigation Trends in the Southeast

Many authors have found that irrigation in the Southeast has increased in the past decades when using acres, farm operations, and water applied as the units of measure (Templeton et. al, 2017; Stubbs, 2016; Perrone, Hornberger, 2014). The descriptive trends shown by including the newest 2017 Census of Agriculture is consistent with the overall trends pre-2017 (Templeton et. al, 2017), with the exceptions of Alabama’s share of irrigated farms (Table 2) and Florida’s share of irrigated acreage on farms with irrigation (Table 3).

Our results show that, overall, Alabama irrigates at a much lower rate than their southeastern counterparts but is moving in a positive direction towards more irrigation, except for in table 3. Further, the increase in irrigation from 2012-2017 is present across all three tables. One reason for this increase could be that Alabama wants to make its agricultural industry more competitive (ALFA, 2018; ALFA, 2017; Auburn, 2012), incentivizing its farmers to irrigate. When using farmland that has irrigation present, I found that the irrigated share actually decreased from 1997-2007 but increased from 2007-2017 (Table 3). This could be due to the fact that Alabama's current polices use tax credits as incentives, therefore encouraging farmers who do not irrigate to begin irrigating (ALFA, 2018; ALFA, 2017). It is possible these policies do not incentivize current farmers to irrigate at a higher rate.

When including the 2017 Census, Florida's trend shows a decrease in the proportion of farm operations that irrigate, an increase in the number of irrigated acres in proportion to total acres of farms with irrigation, and approximately no change in irrigates acres to total agriculture acres. The proportion of irrigated land to agricultural land is supposed to increase over the next few decades (FDACS, 2018), which is consistent with my findings when looking at the proportion of irrigated acres to total farmland (Table 1). Even though the proportion in table 1 decreased from .15639574 to .15612628, the trend seems to be reversing. Counties in northern Florida are projected to increase irrigation at a substantial rate. However, the inverse is projected for southern counties (FDACS, 2018), which could explain the change in Florida's trend. Another reason for these changes could be the result of similar competition issues that are being faced by the western states on water supply. Lastly, we could be seeing a reversal of irrigation adoption in Florida due to a disease called citrus greening, which researchers are beginning to address (FDACS, 2018).

Georgia’s trend of increasing irrigation continued, when accounting for 2017, across all three tables. The trend in proportion of farms irrigating appeared to be leveling off, with 2012 being slightly more than 2007, but when accounting for 2017 we see that the proportion increased substantially again. This is consistent with the literature, finding that Georgia and South Carolina are two out of seven states to have increased irrigation in excess of 50% when examining the time frame of 2003-2013 (Stubbs, 2016). South Carolina, being the other state, also saw the 1997-2012 trend continue into 2017. Georgia’s average proportion across all three tables is very similar to the average of the Southeast region, which could be due to geographical location. One justification for why Georgia is increasing irrigation adoption at such a high rate is the amount of capital invested in informative services teaching farmers new irrigation technologies (Hollis, 2017).

When including the 2017 Census, a new trend begins to emerge regarding North Carolina’s irrigation adoption. All three proportions measured show a decrease in irrigation adoption from 2002-2017, however the shares never decreased below 1997 levels except for the share of farms that irrigate.

One reason for North Carolina’s decreasing share of irrigation adoption could be due to the population boom, with North Carolina being one of the fastest growing states in the nation (EPA, 2010). This coupled with the record setting droughts of 2008 and continued water troubles led to state legislation granting the governor greater regulation of water usage (EPA, 2010). These legislative changes could affect the profit of irrigation technology for the farmer, leading to a lower probability to irrigate.

Analysis of the Incidence of Irrigation during 1997-2017 in Five Southeastern States

The coefficients associated with the proportion of female farmers are negative for all regressions except Florida and are not significant at the 5% level for any regression except for the Southeast. Even though females account for approximately 16% of the Southeastern farmer population, they are .5189 odds more likely to irrigate, meaning that females irrigate substantially less than their male counterparts. Previous studies, that controlled for gender, have mixed results, some finding that gender plays a significant role in terms of irrigation adoption (Mtethiwa et. al, 2012), with others finding no significance (Jackson, 2013; Molnar et. al, 2011). One possibility for our findings that females have a much lower probability of adopting irrigation technology than males is that they, on average, engage in less risky behavior (Harris, Jenkins, 2006). Agricultural irrigation can be extremely costly, ranging from $43 to $146 per acre dependent upon the form of irrigation used (Hogan et. al, 2007), making the investment in irrigation risky for farmers. Another justification is that female farmers are less likely to take on irrigation adoption is due to them not being as emotionally, and occupationally, invested in farming as men. This is due to female farmers having "severe difficulties in describing their roles and identifying their occupation, often unable to describe their farm work as an occupation at all" (Brandth, 2002). This lack of investment could disincentivize female farmers from trying to improve the quality and output of their current production through irrigation practices.

The variable measuring the proportion of farmers over 65 is negative and significant at the regional level. However, at the state level the findings were much less conclusive, with all five states finding the proportion to not be significant at the 5% level. Some states estimated a positive relationship (South Carolina and Florida) while others estimated negative relationships (Alabama, Georgia, and North Carolina). The literature regarding the effect of age is mixed, with some studies finding it to be significant, and others finding it to be statistically indistinguishable from zero (Chuchird, Sasaki, & Abe, 2017; Molnar, 2011; Koundouri, Nauges, and Tzouvelekas, 2006). However, since our variable is the proportion of farmers over 65, we would expect there to be a more substantial result than the traditional age variables used in other papers. Justifications for the significance of the age variable is that older farmers are less likely to invest in new adoption practices due to a desire to retire in the near future, and/or a lack of desire to learn new technologies.

On the regional level average farm size was significant at the 1% level, whereas machinery assets per acre was not significant even on the 10% level. When examining the effect of farm size on irrigation adoption, using cotton farmers as the sample, farm size is shown to not have a significant effect (Pokhrel, Paudel, Segarra, 2018). My findings are not consistent with this, finding that farm size is significant across the Southeast, as well as in Georgia and Alabama. Very few authors have incorporated machinery assets per acre into their regressions, therefore there is not much literature to compare. A possible justification for the positive coefficients estimated is that if a farmer is more likely to invest in land, or high value machinery for her farm, she is also willing to invest in irrigation technology. This could stem from the farmer having a high-risk threshold. Additionally, both variables could be indicators of a greater dedication to farming, therefore increasing the probability of a farmer to invest in irrigation technology.

Machinery assets per acre and average farm size are the two ways I controlled for collateral and credit access. Multiple authors have examined the relationship between access to credit and irrigation adoption, due to the fact that easier access to credit, and lower interest rates, lower the financial burden and encourage adoption. These studies have found this relationship to be positive and significant (Raut et. al, 2011; Mohamed, Temu, 2008). Therefore, bad, or no, access to credit can lead to “low productivity and production and hence low income” for farm households (Mohamed, Temu, 2008). While machinery assets per acre is not significant, average farm size is, and a positive coefficient is estimated for both variables in every regression. Another reason for farm size being correlated with the probability of a farmer to adopt irrigation technologies is due to fixed costs, a similar argument was made in the Templeton et. al (2018) study regarding a farmer’s usage of climate forecasts. The total fixed costs of the necessary equipment to begin irrigating can exceed tens of thousands of dollars for the farmer (Hogan et. al, 2007), therefore, a larger farm would have a lower fixed cost per acre, and therefore, most likely a higher probability to irrigate. Therefore, the value a farmer has in physical assets is correlated with a higher adoption of irrigation when using my sample.

The proportion of farmers whose occupation is not farming is negative for every state except Alabama, and significant across three out of the six regressions. The coefficient on the regional level is the only variable whose absolute value is greater than one, estimating that not being primarily a farmer has a large influence on whether or not that farmer irrigates. These results are consistent with the Mumin (2017) findings regarding Ghana. This is due to the fact that farmers are more inclined to improve “their access-to-essential services through farming,” substantiated by the “negative, direct effect of off-farm income on access-to-essential services” (Mumin, 2017). Time is a major hurdle, in terms of agricultural practices, when it comes to farmers who primarily engage in other occupations, leading to the farmer having less of an incentive to invest in irrigation technologies. (Mango et. al, 2018). Another justification for such a large, negative coefficient associated with this variable is that farmers with off farm income can withstand periods of negative farm income and aren’t as penalized by droughts and water shortages as farmers who have a primary occupation of farming.

Each year indicator is significant at the 5% level in nearly every regression, with the only exception being the state level Alabama regression. One justification for this is that the weather at the time of each census could be significantly different between the years, such as the extreme drought in North Carolina during 2008 (EPA, 2010). The main difference between the results found in this paper and Jackson’s (2013), when discussing the Southeast region, is that the proportion of female farmers was found to be significant in our model. However, the proportion of farmers who are primarily employed as nonfarmers, the proportion of farmers over the age of 65, and the average farm size were all found to be significant in both models. It is possible that when extending the dataset, the importance of gender becomes more significant in 1997-2017 than it was in 2002-2007.

CONCLUSION

The proportion of farmers whose occupation is not farming, the proportion of farmers over 65, the proportion of female farmers, and the average size of a farm in an arbitrary county in the Southeastern U.S. all significantly affect the proportion of farmers who irrigate in the county. Most of the estimates in this paper are consistent with the estimates in Jackson's (2013) paper. Inclusion of the value of machinery assets per acre, a variable not included in Jackson's previous study, and data from the 1997, 2012, and 2017 Censuses of Agriculture has allowed me to estimate a more complete and more accurate picture.

Due to time and data limitations there are improvements that can be made to more accurately determine the true effect of these variables, and others, on the entire southeastern population of farmers. The mean years of agricultural experience of farmers in a county might affect the decision of a farmer to irrigate, and therefore by including this variable I could improve the model. Further, including drought binary variables at the time of the census, and using a certain threshold to define a drought, would allow for me to control for the effects of said drought on irrigation adoption in the county, improving the model as well. Both of these changes would show a truer estimation of these variables, providing more clarity and conciseness to the model.

While I did not include these variables, I have the benefit of including the recent 2017 Census of Agriculture providing a longer time period of observations, which should improve the estimates obtained. While my model cannot be directly used by extension agents to more accurately target their audience, it does provide the basis for further studies. Knowing that female farmers are significantly correlated with a lower probability of irrigation adoption in the Southeast does not inform extension agents that they need to target female farmers, but rather that they need to look at the marginal benefit of extension to female farmers to determine the impact of their services.

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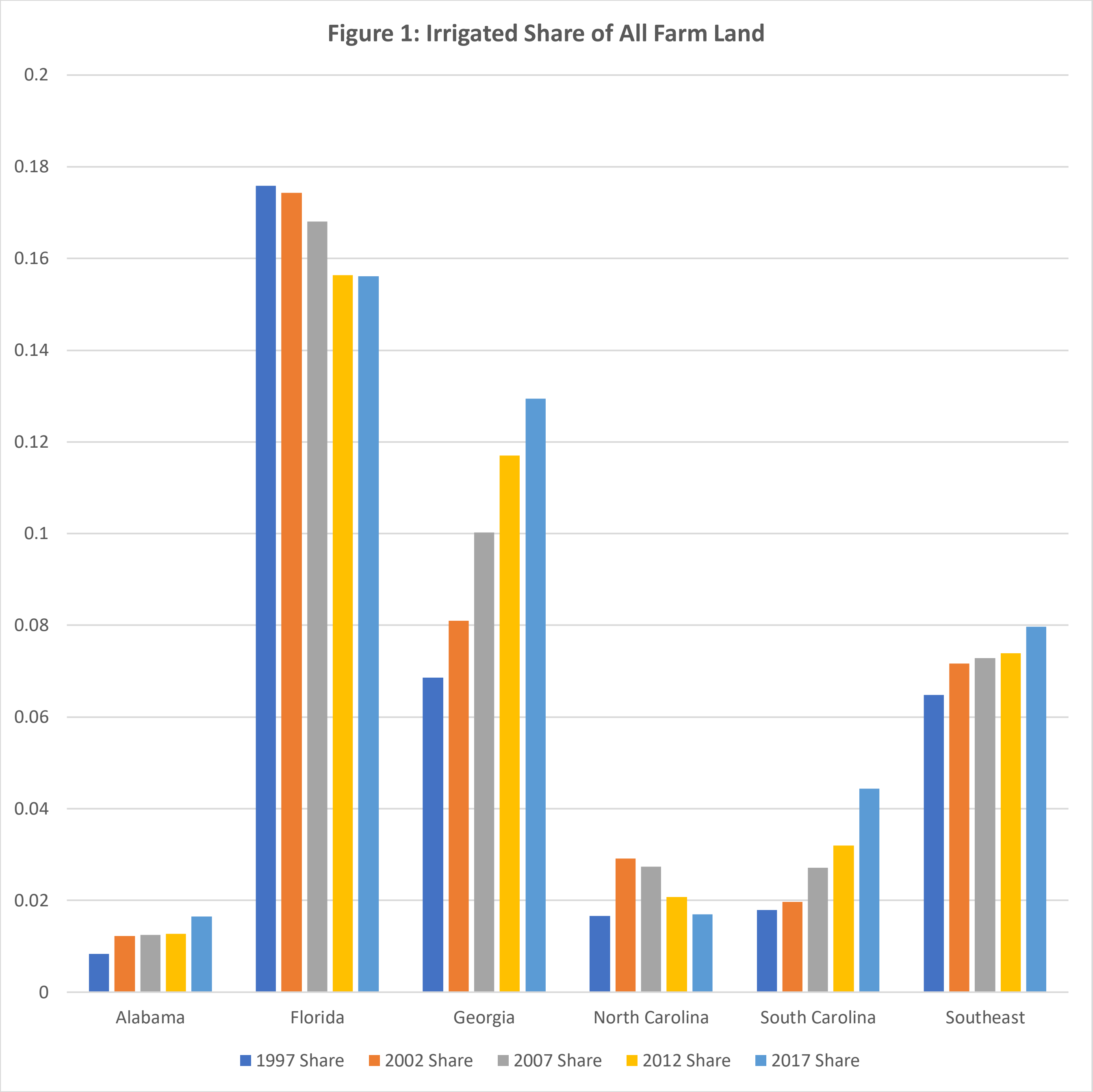Figure 1: Irrigated Share of All Farm Land
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Alabama
Florida
Georgia
North Carolina
South Carolina
Southeast
1997 Share
2002 Share
2007 Share
2012 Share
2017 Share

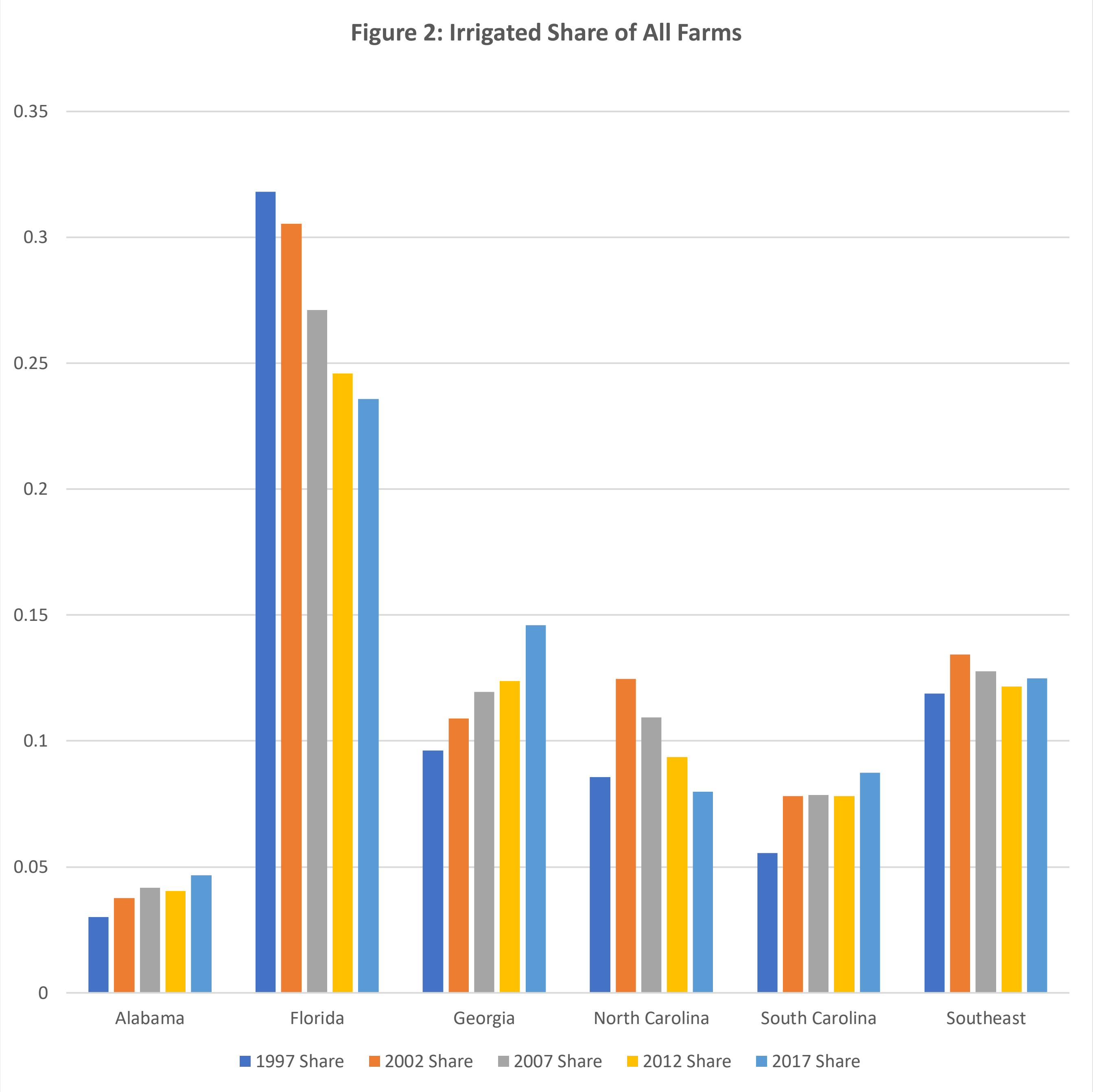
Figure 2: Irrigated Share of All Farms
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Alabama
Florida
Georgia
North Carolina
South Carolina
Southeast
1997 Share
2002 Share
2007 Share
2012 Share
2017 Share

Figure 3: Irrigated Share of Irrigating Farm Area

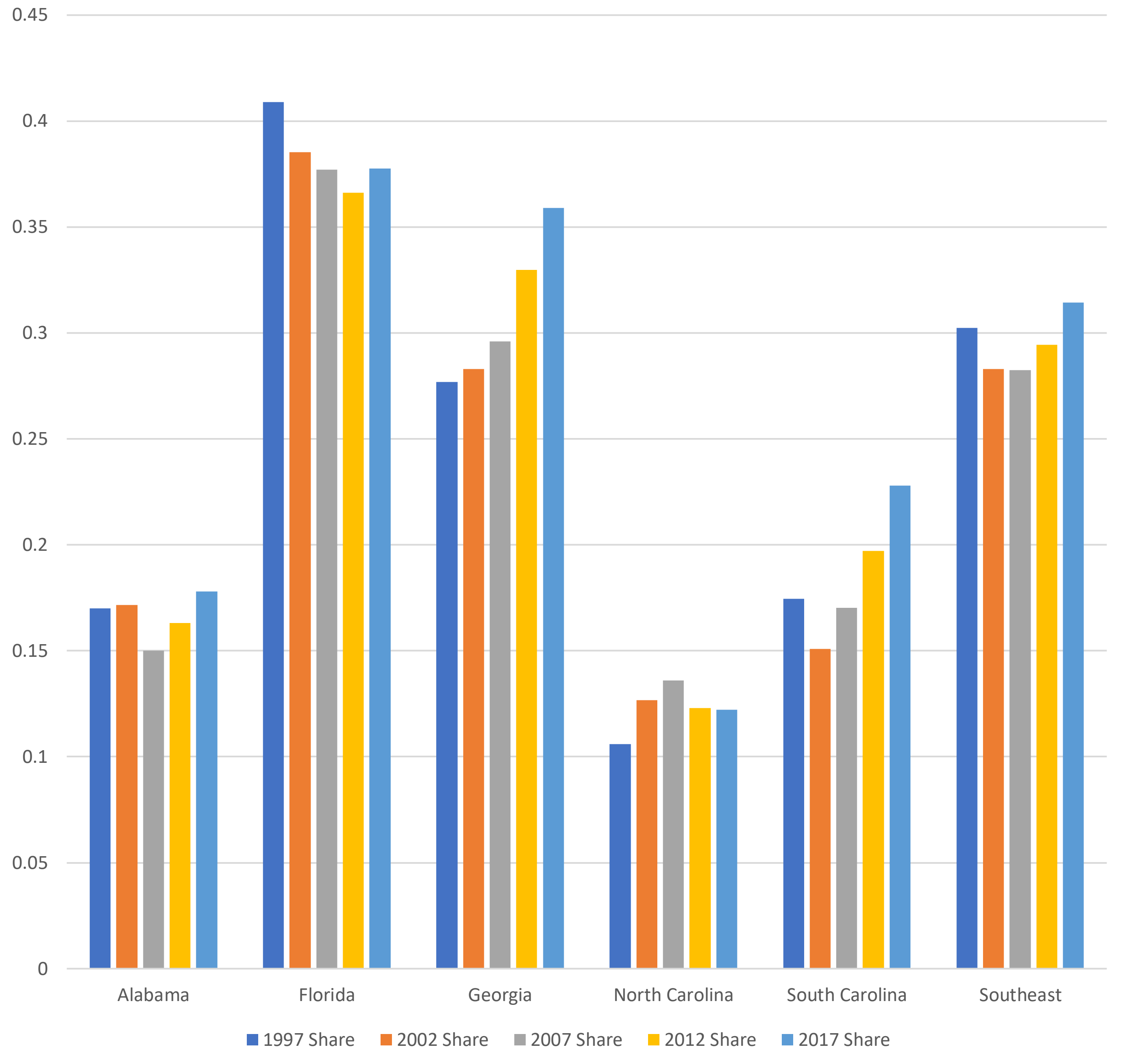

Table 1: Irrigated Area and All Farmland by State(s), 1997-2017

Year	# of Acres	Alabama	Florida	Georgia	North Carolina	South Carolina	Southeast
1997	Irrigated Acres	79,647	1,873,823	773,066	156,315	88,898	2,971,749
	Total Acres	9,517,377	10,659,777	11,262,838	9,444,867	4,974,138	45,858,997
	Share (Percent)	**0.0084 (0.84)**	**0.1758 (17.58)**	**0.0686 (6.86)**	**0.0166 (1.66)**	**0.0179 (1.79)**	**0.0648 (6.48)**
2002	Irrigated Acres	108,783	1,815,174	870,810	264,057	95,642	3,154,466
	Total Acres	8,904,387	10,414,877	10,744,239	9,079,001	4,845,923	43,988,427
	Share (Percent)	**0.0122 (1.22)**	**0.1743 (17.43)**	**0.0810 (8.10)**	**0.0291 (2.91)**	**0.0197 (1.97)**	**0.0717 (7.17)**
2007	Irrigated Acres	112,819	1,552,118	1,017,773	232,075	132,439	3,047,224
	Total Acres	9,033,537	9,231,570	10,150,539	8,474,671	4,889,339	41,779,656
	Share (Percent	**0.0125 (1.25)**	**0.1681 (16.81)**	**0.1003 (10.03)**	**0.0274 (2.74)**	**0.0271 (2.71)**	**0.0729 (7.29)**
2012	Irrigated Acres	113,008	1,493,320	1,125,355	174,526	159,239	3,065,448
	Total Acres	8,902,654	9,548,342	9620836	8,414,756	4,971,244	41,457,832
	Share (Percent)	**0.0127 (1.27)**	**0.1564 (15.64)**	**0.1170 (11.70)**	**0.0207 (2.07)**	**0.0320 (3.20)**	**0.0739 (7.39)**
2017	Irrigated Acres	142,001	1,519,379	1,287,541	143,444	210,437	3,302,802
	Total Acres	8,580,940	9,731,731	9,953,730	8,430,522	4,744,913	41,441,836
	Share (Percent)	**0.0165 (1.65)**	**0.1561 (15.61)**	**0.1294 (12.94)**	**0.0170 (1.70)**	**0.0444 (4.44)**	**0.0797 (7.97)**

[1.] State Level Data

Table 2: Number of Farms with Irrigated Land and All Farms by State(s), 1997-2017

Year	# of Farms	Alabama	Florida	Georgia	North Carolina	South Carolina	Southeast
1997	Irrigated Farms	1,503	14,573	4,752	5,059	1,435	27,322
	Total Farms	49,872	45,808	49,343	59,120	25,807	229,950
	Share (Percent)	**0.0301 (3.01)**	**0.3181 (31.81)**	**0.0963 (9.63)**	**0.0856 (8.56)**	**0.0556 (5.56)**	**0.1188 (11.88)**
2002	Irrigated Farms	1,698	13,456	5,369	6,721	1,918	29,162
	Total Farms	45,126	44,081	49,311	53,930	24,541	216,989
	Share (Percent)	**0.0376 (3.76)**	**0.3053 (30.53)**	**0.1089 (10.89)**	**0.1246 (12.46)**	**0.0782 (7.82)**	**0.1344 (13.44)**
2007	Irrigated Farms	2,035	12,868	5,716	5,788	2,030	28,437
	Total Farms	48,753	47,463	47,846	52,913	25,867	222,842
	Share (Percent)	**0.0417 (4.17)**	**0.2711 (27.11)**	**0.1195 (11.95)**	**0.1094 (10.94)**	**0.0785 (7.85)**	**0.1276 (12.76)**
2012	Irrigated Farms	1,747	11,744	5,230	4,699	1,973	25,393
	Total Farms	43,223	47,740	42,257	50,218	25,266	208,704
	Share (Percent)	**0.0404 (4.04)**	**0.2460 (24.60)**	**0.1238 (12.38)**	**0.0936 (9.36)**	**0.0781 (7.81)**	**0.1217 (12.17)**
2017	Irrigated Farms	1,891	11,228	6,191	3,708	2,167	25,185
	Total Farms	40,592	47,590	42,439	46,418	24,791	201,830
	Share (Percent)	**0.0466 (4.66)**	**0.2359 (23.59)**	**0.1459 (14.59)**	**0.0799 (7.99)**	**0.0874 (8.74)**	**0.1248 (12.48)**

[1] State Level Data

Table 3: Irrigated Area and Land of Farms that Irrigate by State(s), 1997-2017

Year	# of Acres	Alabama	Florida	Georgia	North Carolina	South Carolina	Southeast
1997	Irrigated Acres	79,647	1,873,823	773,066	156,315	88,898	2,971,749
	Total Acres	468,865	4,581,105	2,791,628	1,475,836	509,201	9,826,635
	Share (Percent)	**0.1699 (16.99)**	**0.4090 (40.90)**	**0.2769 (27.69)**	**0.1059 (10.59)**	**0.1746 (17.46)**	**0.3024 (30.24)**
2002	Irrigated Acres	108,783	1,815,174	870,810	264,057	95,642	3,154,466
	Total Acres	634,369	4,709,504	3,076,482	2,086,433	634,367	11,141,155
	Share (Percent)	**0.1715 (17.15)**	**0.3854 (38.54)**	**0.2831 (28.31)**	**0.1266 (12.66)**	**0.1508 (15.08)**	**0.2831 (28.31)**
2007	Irrigated Acres	112,819	1,552,118	1,017,773	232,075	132,439	3,047,224
	Total Acres	751,005	4,116,545	3,439,646	1,706,053	777,695	10,790,944
	Share (Percent)	**0.1502 (15.02)**	**0.3770 (37.70)**	**0.2959 (29.59)**	**0.1360 (13.60)**	**0.1703 (17.03)**	**0.2824 (28.24)**
2012	Irrigated Acres	113,008	1,493,320	1,125,355	174,526	159,239	3,065,448
	Total Acres	692,630	4,076,675	3,413,743	1,420,621	807,926	10,411,595
	Share (Percent)	**0.1632 (16.32)**	**0.3663 (36.63)**	**0.3297 (32.97)**	**0.1229 (12.29)**	**0.1971 (19.71)**	**0.2944 (29.44)**
2017	Irrigated Acres	142,001	1,519,379	1,287,541	143,444	210,437	3,302,802
	Total Acres	797,224	4,023,767	3,587,390	1,175,133	923,351	10,506,865
	Share (Percent)	**0.1781 (17.81)**	**0.3776 (37.76)**	**0.3589 (35.89)**	**0.1221 (12.21)**	**0.2279 (22.79)**	**0.3143 (31.43)**

[1] State Level Data

Table 4: Summary Statistics of Logit Model Variables

Location		**FARMSIZE**	**MASSETPACRE**	**NONFARM**	**FEMALE**	**OLD**	**ANYIRR**
Units of Measure		(Acres)	(2017 $ per Acre)	(Share of Farmers)			Share of Acres
Southeast	Mean	239.271	457.000	0.544	0.159	0.330	0.122
	Std. Dev.	180.966	520.008	0.087	0.070	0.072	0.109
	Min.	4.175	31.602	0.111	0.009	0.000	0.003
	Max.	1766.017	16173.650	0.857	0.553	0.739	0.747
	Observations	2185	2184	2195	2192	2195	2177
Alabama	Mean	232.605	341.539	0.570	0.136	0.334	0.042
	Std. Dev.	110.831	149.924	0.074	0.050	0.063	0.029
	Min.	84.507	83.920	0.383	0.052	0.195	0.003
	Max.	602.930	865.351	0.765	0.218	0.517	0.198
	Observations	335	335	335	335	335	334
Florida	Mean	263.748	515.253	0.542	0.215	0.334	0.235
	Std. Dev.	281.625	1154.696	0.071	0.084	0.067	0.157
	Min.	4.175	31.602	0.150	0.024	0.043	0.018
	Max.	1766.017	16173.65	0.754	0.441	0.533	0.747
	Observations	330	330	335	334	335	330
Georgia	Mean	241.535	428.461	0.555	0.161	0.335	0.129
	Std. Dev.	164.465	255.078	0.081	0.065	0.077	0.097
	Min.	13.765	72.966	0.273	0.012	0.125	0.003
	Max.	992.286	1908.943	0.857	0.553	0.739	0.513
	Observations	795	794	795	793	795	786
North Carolina	Mean	219.845	581.235	0.491	0.133	0.314	0.110
	Std. Dev.	172.334	381.655	0.100	0.061	0.074	0.075
	Min.	14.898	161.738	0.111	0.009	0.000	0.004
	Max.	904.884	7142.207	0.734	0.333	0.469	0.571
	Observations	495	495	500	500	500	497
South Carolina	Mean	245.222	372.692	0.587	0.162	0.338	0.081
	Std. Dev.	139.527	150.883	0.065	0.057	0.061	0.048
	Min.	53.150	116.004	0.299	0.064	0.189	0.011
	Max.	881.915	934.575	0.758	0.281	0.567	0.307
	Observations	230	230	230	230	230	230

[1] County Level Data

Table 5: Coefficient Estimates of Logit Model of the Probability that a Farmer Irrigates

Variable	**Southeast**	**Alabama**	**Florida**	**Georgia**	**North Carolina**	**South Carolina**
FARMSIZE	0.0006***	0.0019**	0.0001	0.0015***	0.0003	0.0004
	(0.0002)	(0.0009)	(0.0002)	(0.0004)	(0.0004)	(0.0006)
MASSETPACRE	2.99e-06	0.0009**	5.58e-06	0.0001	0.0001	0.0005
	(0.0000)	(0.0050)	(0.0000)	(0.0001)	(0.0001)	(0.0003)
NONFARM	-1.2079***	0.1067	-0.3511	-1.0347***	-1.3283***	-0.7062
	(0.1704)	(0.6278)	(0.3777)	(0.2689)	(0.3321)	(0.5084)
FEMALE	-0.6560**	-0.3184	0.6225	-0.0051	-0.2561	-1.3464*
	(0.2585)	(1.3472)	(0.4713)	(0.3803)	(0.5988)	(0.7940)
OLD	-0.4686**	-0.3218	0.8306*	-0.6030*	-0.7323	0.2971
	(0.2219)	(0.8347)	(0.4488)	(0.3244)	(0.5087)	(0.6285)
YEAR 2002	0.1471***	0.2103	-0.1083*	0.1617***	0.3437***	0.3775***
	(0.0335)	(0.1320)	(0.0646)	(0.0528)	(0.0668)	(0.0793)
YEAR 2007	0.3077***	0.3213**	-0.2120***	0.3256***	0.3615***	0.4267***
	(0.0313)	(0.1058)	(0.0654)	(0.0560)	(0.0605	(0.0837)
YEAR 2012	0.2620***	0.2376*	-0.2779***	0.4048***	0.2235***	0.3243***
	(0.0372)	(0.1241)	(0.0701)	(0.0665)	(0.0745)	(0.0923)
YEAR 2017	0.3757***	0.3757*	-0.4124***	0.5676***	0.0537	0.5050***
	(0.0522)	(0.2040)	(0.1212)	(0.0810)	(0.1150)	(0.1483)
CONSTANT	-1.7041	-4.2681	-1.4231	-2.1826	-1.6709	-2.6704
	(0.1319)	(0.5495)	(0.3044)	(0.2284)	(0.2174)	(0.4818)

Parentheses correspond to standard error

Observations used in the model was 2,167

* Corresponds to 10% level ** Corresponds to 5% level *** Corresponds to 1% level

Table 6: Marginal Effects on the Probability that a Farmer Irrigates

Variable	**Southeast**	**Alabama**	**Florida**	**Georgia**	**North Carolina**	**South Carolina**
FARMSIZE	0.0001	0.0001	0.0000	0.0002	0.0000	0.0000
MASSETPACRE	2.80e-07	0.0000	8.75e-07	0.0000	4.68e-06	0.0000
NONFARM	-0.1133	0.0040	-0.0550	-0.1045	-0.1197	-0.0502
FEMALE	-0.0615	-0.0120	0.0976	-0.0005	-0.0231	-0.0958
OLD	-0.0439	-0.0122	0.1302	-0.0609	-0.0660	0.0211