Land Tenure, Conservation Tillage, and Other Risk Management Practices

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LAND TENURE, CONSERVATION TILLAGE, AND OTHER RISK MANAGEMENT PRACTICES

by

Xiaolin Zhou

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As members of the Master's Committee, we certify that we have read the thesis prepared by: Xiaolin Zhou
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DEDICATION

I dedicate this thesis to my beloved family, who have always supported me unconditionally and encouraged me along the way.

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ABSTRACT

The goal of this study is to test the effect of tenure on adoption on three risk reduction practices: conservation tillage, irrigation, and crop insurance. It also assesses how different risk reduction practices interact with each other. The study used stratified data from the USDA Census of Agriculture 2012 and 2017 surveys that divide observations into state-tenure status-year triplets. The Census divided farm data between full owners, partial owners, and full tenants. Univariate analysis found no negative affect of land leasing on conservation tillage adoption. In multiple regression analysis, however, there was evidence that part ownership was negatively associated with adoption of no till. No difference in adoption between full owners and full tenants was found.

Irrigation adoption was greater in triplets in states with lower average annual precipitation, longer growing seasons, and warmer planting seasons. Irrigation adoption rates were lower in states with greater soil erosion. Some factors that contribute to greater soil erosion, such as steeper slopes or soils with lower water holding capacity, also contribute to poorer irrigation performance. Experiencing drought over the previous five years was not found to increase state-level adoption of irrigation.

Past findings on the relationship between crop insurance and adoption of conservation tillage have been mixed. Some studies have found a negative association between the two, while other research suggests that crop insurance is not a barrier to conservation tillage adoption. We found no statistically significant association between crop insurance enrollment and conservation tillage adoption rates.

Adoption of both reduced tillage and no till were lower in states with higher irrigation adoption rates. Controlling for other factors, this negative relationship was strong and statistically significant. This suggests that irrigation and conservation tillage might be substitute strategies for adapting to low soil moisture production

conditions.

This study applied instrumental variable and simultaneous equation methods to account for the possibility of the endogeneity of tillage, insurance, and irrigation choice. For the different practice adoption (and enrollment) equations, results were sensitive to model specification (e.g. between reduced form least squares, two-stage instrumental variable, and three stage least squares methods). Also, it was found that the instruments used in the present study were weak instruments. Future simultaneous equation modeling would benefit from identification and use of stronger instruments.

CHAPTER 1

Introduction

There are long standing debates about how tenure affects conservation tillage adoption. Finding the answer to this question becomes even more important recently for two reasons. First, tenure patterns in the U.S. have dramatically changed. The percentage of cropland operated by full tenants (those not owning any of the land they operate) has seen a drastic decrease since 1935. Although the share of owner-operators has remained stable since 1964, there has been a significant shift from land being managed by full owners (operating only owned land) to land being operated by part owners (farmers operating a mix of owned and leased in land). Part owners operated 54% of the cropland in 2012—a 115% increase compared to 1935 (Bigelow et al., 2016). Conservation tillage can improve long-term land productivity, but requires some initial costs, which can lower short-run profits. A common argument is that farmers leasing land will be less likely to adopt conservation tillage because they may not be farming the land long enough to capture those long-term productivity benefits.

Second, conservation tillage can maintain soil moisture, and so mitigate negative effects of drought. In the age of global climate change, extreme weather events appear more often, increasing agricultural production risks. This highlights the importance of conservation tillage as a mechanism to adapt to drought, heat, and other aspects of climate change.

Conservation tillage was born in the era of the Dust Bowl, which resulted from drought and deep plowing. It has since been promoted by the USDA Natural Resource Conservation Service through programs providing both technical and financial assistance. Previous empirical research[1] has shown conservation tillage adoption is associated with operators' education and experience (Ervin and Ervin, 1982;

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[1] See Knowler and Bradshaw (2007) for a comprehensive synthesis of the literature.

Rahm and Huffman, 1984), awareness of erosion (Gould et al., 1989), farm size, (Ervin and Ervin, 1982; Rahm and Huffman, 1984; Davey and Furtan, 2008; Lee and Stewart, 1983) erosion (Wu and Babcock, 1998; Ervin and Ervin, 1982; Ding et al., 2009; Schoengold et al., 2015; Soule et al., 2000), weather, (Ervin and Ervin, 1982; Ding et al., 2009; Schoengold et al., 2015; Davey and Furtan, 2008; Ugalde et al., 2007), and costs of adoption (Ding et al., 2009). Of course, tenure has also been found to affect adoption of agricultural conservation practices, including conservation tillage. Results have been mixed, though. For example, Lee and Stewart (1983) found no difference in no-till adoption among three tenure classes, while Belknap and Saupe (1988); Lynne et al. (1988) both found full owners were more likely to adopt conservation tillage. A study of part owners found no difference in conservation tillage adoption on owned versus rented land (Deaton et al., 2018). Evidence from the USDA Agricultural Resources Management Survey(ARMS) showed that owners and share-renters were more likely than cash-renters to adopt conservation tillage (Soule et al., 2000).

The Federal government's responses to the Dust Bowl did not stop at promoting conservation practices. The establishment of federal crop insurance is also an effort to protect farmers from production risks. Though not successful initially, enrollment later boomed because of program changes and large premium subsidies provided by the federal government. This has made crop insurance another major risk management tool. Because conservation tillage and crop insurance can reduce certain production risks, they may be substitutes for each other. Recent research has shed light on the effect of crop insurance on conservation tillage adoption but has reached different conclusions. Crop insurance has been found to have a significantly negative effect on conservation tillage adoption in two studies (Ding et al., 2009; Schoengold et al., 2015) but not pose a barrier to conservation tillage adoption in another (Fleckenstein et al., 2020). Crop insurance enrollment itself is associated with farm biophysical factors and farmer characteristics. Tenure may also play a role in crop insurance enrollment as landlords may require tenants to purchase insurance.

Irrigation is another means of mitigating risks from insufficient rainfall and soil moisture. As a tool to artificially control moisture, irrigation assists with agriculture productivity in dry areas and in years with insufficient rainfall. One might hypothesize that irrigation is a substitute for other risk reduction practices. (Wu and Babcock, 1998) However, empirical results have not been conclusive. Studies have reported that irrigation discourages conservation tillage (Fuglie, 1999; Mitchell et al., 2007; Wade and Claassen, 2017), but other research suggests irrigation encourages conventional tillage (Fuglie, 1999).

The goal of this paper is to test the effect of tenure on adoption on three risk reduction practices: conservation tillage, irrigation, and crop insurance. It also assesses how different risk reduction practices interact with each other. We estimate conservation tillage practice adoption as a function of tenure status, a rich set of fixed effects and control variables, as well as irrigation adoption and crop insurance program participation. To account for possible endogeneity of the insurance and irrigation variables, we apply an instrumental variable (IV) approach. Finally, we estimate a system of equations that treats tillage choice, irrigation adoption, and crop insurance enrollment as simultaneously determined variables. Previous research has examined the effects of crop insurance on conservation tillage adoption in predominantly non-irrigated production in the US Midwest. (Ding et al., 2009; Schoengold et al., 2015) That work also focused on conservation tillage as a drought mitigation strategy. This paper also considers the role of crop insurance on tillage, but also considers the role of irrigation as a substitute strategy to lower risks from drought and low soil moisture. Our analysis also extends across the entire United States. While past research has considered the effects of irrigation, drought, crop insurance, and tenure status on conservation tillage, this study is the first to our knowledge that considers all these factors together. The paper proceeds as follows: Chapter 2 provides background information and details on existing literature, Chapter 3 describes data, Chapter 4 gives empirical strategy and results, Chapter 5 concludes.

CHAPTER 2

Background Information

The Dust Bowl and Tillage The American Dust Bowl of the 1930s was a tragedy in the history of U.S. agriculture, which took several years to mitigate (Hornbeck, 2012). The Homestead Act of 1862 enabled adults in the U.S. to claim 160 acre of land for farming. Half a century later, Congress legislated the Enlarged Homestead Act of 1909, which doubled the acres allowance for farmers. Many farmers obtained access to marginal lands[1] in the Plains to promote dryland farming. This series of acts brought a massive influx of new farmers lacking agricultural experience and understanding of nature to the Great Plains region. This misunderstanding of the ecology of the Great Plains led to improper use of plowing. This subsequently caused extensive soil erosion throughout the entire region *circa* 1930s. Another contributing factor was drought caused by anomalous tropical sea surface temperatures (Schubert et al., 2004),

Plowing is one of the operations to achieve intensive tillage (also known as conventional tillage), which is an ancient technique developed by our ancestors. By digging, stirring, overturning and finally removing over 85% crop residue, intensive tillage helps better prepare seedbeds, control weeds, and mix nutrients. However, farmers at that time were unaware of the byproducts brought by intensive tillage. Loosened topsoil exposed to sun and air was not capable of maintaining soil moisture. Wind erosion, especially in high wind areas was also a problem. Then came the unstoppable dust storms that picked up more than 75% of precious topsoil and damaged these lands for several decades. Not only was agricultural productivity and land values reduced (Hornbeck, 2012) , the Dust Bowl also substantially affected air quality and human health (Goudie, 2020).

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[1] Land that is not profitable to farm.

The silver lining of the Dust Bowl is that public started to pay attention to the sustainability of agriculture and developed conservation practices. The establishment of the USDA Natural Resource Conservation Service, originally named the Soil Conservation Service, marked a turning point where the federal government began to promote soil conservation. Among all conservation practices, conservation tillage is a key component of a soil conservation system (Claassen et al., 2018). It is important to understand farmers' decision-making process regarding conservation tillage adoption, as it is the foundation of making effective policy to promote its adoption.

Two subsets of conservation tillage are reduced-till (Strip-till and mulch-till are both reduced-till.) and no-till. While reduced-till has less than 80 Soil Tillage Intensity Rating[2]. No-till is the practice of refraining from tilling the soil. Benefits of conservation tillage include reducing soil evaporation, enhancing soil quality, anchoring soil in place, and lowering labor and fuel cost. These benefits ultimately make soil less likely to erode especially when there is a disaster or abnormal climate (For instance, high wind and high temperature as occurred during the Dust Bowl.). Therefore farmers may also consider conservation tillage as a risk reduction practice (Schoengold et al., 2015).

There is a rich existing literature on factors affecting tillage adoption. As one of the earliest, Ervin and Ervin (1982) model the decision-making process for the use of soil conservation practices and test the model with micro-data sampled in Monroe County, MI. They find the use of conservation practices is associated with personal e.g. education, physical e.g. erodibility, institutional e.g. cost-sharing, and economic e.g. farm type, factors.

Rahm and Huffman (1984) utilize Iowa corn farm micro-data to study the key variables affecting adoption of conservation tillage (They use the term "reduced-till" although their definition of "reduced-till" is a sum of no-till and reduced till in

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[2] The Soil Tillage Intensity Rating is an index created by USDA NRCS to measure soil disturbance. The range is 0-200 as high values means higher tillage intensity. (USDA Natural Resources Conservation Service, 2008)

their paper). They show cropping systems, farm size, and soil type determine the adoption.

Similar research has been done worldwide. A study using Canadian census data, Davey and Furtan (2008) investigates the factors that affect conservation tillage adoption in the Prairie region. It found that farm size, proximity to a research station, soil type, and weather conditions are important explanatory variables. Ugalde et al. (2007) suggest climate change is driving a shift from intensive tillage to conservation tillage in Australia.

Wu and Babcock (1998) consider the adoption of multiple conservation practices (conservation tillage, crop rotation, and soil testing) They note that prior research focused on adoption of individual practices in isolation, treating the adoption of other practices exogenous. In contrast, they treat different conservation practices as being determined jointly and demonstrate the importance of this specification. They found that farmers who adopted both conservation tillage and crop rotations reduced erosion more than those who only adopted just one of these practices. This suggests that multiple conservation practices might have synergistic effects.

Knowler and Bradshaw (2007) summarize previous research on farmers' conservation practice adoption. They conclude that to promote conservation agriculture, different strategies should be used for different practices. The research provides insight of factors that affecting conservation tillage adoption.

Land Tenure Since land is the primary input in agricultural production, land tenure could largely shape farmers' decision-making pattern regarding conservation practices. Understanding the role of tenure in farmers' behavior in conservation practices adoption is essential in tailoring the policy to promote sustainable agriculture. USDA classifies farms into 3 different tenure classes in its Census of Agriculture. When operators own all the land they operate, they are classified as full owners. Operators who lease in all the land they operate are classified as tenants. Part-owners operate a combination of land they own and land they lease in from others. Partial owners may lease in varying shares of the land they operate. The percentage of farmland acres operated by full owners has remained stable since 1964[3]. The percentage shows a slow decreasing pattern. In 1964, it was around 65%. It hit a record low 58% in 1992 and bounces back to just above 60% in 2012. However, the share of acres operated by tenants in 2012 decreased drastically compared to 1935 while land operated by part owners grew from 25% to 54%.

It has long been argued that non-owner operators are more likely to abuse the land they rent. McConnell (1983) developed a dynamic model of soil conservation, considering different incentives for owned, rented, and corporate farms. Because tenants do not care about the farm resale value, they have less incentive to adopt soil conservation practices unless they are necessary to maintain short-run productivity. Lichtenberg (2007) proposed a multi-task principal-agent model to challenge this argument. He argued that landlords have an incentive to maintain the productivity of their land. He examines the scope for landlords to make conservation investments and structure rental contracts to encourage conservation. Different outcomes are possible if the tenant is risk loving, risk neutral, or risk averse.

Previous empirical research linking land tenure and farmers' decision on conservation practices yields distinct results. Lee and Stewart (1983) was the first to analyze the relationship between land tenure and no-till using national data. They state that since no-till as a conservation practices does not require long-term investment, there is no obstacle for tenants to adopt such practices, and therefore, there is no difference across three tenure classes. Their results indicate that full owners and part owners with relatively small holdings of the land have lower no-till adoption rates. They also show small farm size is a more important factor affecting no-till adoption than tenure class. However, in contrast, Belknap and Saupe (1988) and Lynne et al. (1988) find full owners are more likely than tenants to adopt conservation practices.

The literature has been expanded by Soule et al. (2000) using lease type to separate tenants. According to contract type, tenants consist of cash renters and

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[3] Acres operated by owners include all the acres in the full owner category plus acres owned by part owner.

share renters. They find cash renters is less likely than owners and share renters to adopt conservation tillage. Both types of tenants are less likely to be involved in conservation practices that require large investment and a longer term to generate benefits such as grassed waterways, contour farming and strip cropping. Recently, Deaton et al. (2018) use Canadian survey data to study exclusively part owners' conservation practices adoption. Being able to identify the rental relationship and landlord type for land rented by part owners, they find there is no difference in adoption of machinery-related practices especially conservation tillage between land owned and rented by part owners. They also determine that because of tenure insecurity, part owners are less likely to use cover crops that generate returns over a longer term on their rented land.

Crop Insurance In the United States, farmers can purchase crop insurance, which is heavily subsidized by the federal government, to manage risk. The USDA Risk Management Agency (RMA) oversees insurance policies available for more than 100 crops and livestock commodities. There are three major types of crop insurance. Yield-based insurance protects farmers from low yield. Revenue insurance offers farmer gross income protection, regardless of whether loss is caused by low yield or low commodity prices. Index insurance makes indemnity payments based on a yield index instead of individual loss, protecting farmers from widespread risks. Revenue insurance and index insurance make up a large part of crop insurance, as yield-based insurance enrollment is phasing out. Crop insurance enrollment has grown ever since the passage of the Federal Crop Insurance Reform Act of 1994. In 2019, over 400 million acres were enrolled in crop insurance, accounting for more than 90% of planted crop acres.

Moral hazard and adverse selection are two key concerns with crop insurance. Adverse selection occurs when those purchasing insurance have more information than insurers. For example, farmers operating on land with poor soil quality face more risk, which means crop insurance is more valuable for them. As a result, given same premium, high risk farmers are more likely to enroll. Adverse selection has become less of a problem because of the high enrollment rate as low-risk and high-risk farmers are both insured. However, moral hazard has been discussed more often as the federal crop insurance program has expanded. Studies of the impact of crop insurance on the environment has reached mixed conclusions. Using samples of Kansas wheat farmers, Smith and Goodwin (1996) confirm the conventional wisdom that crop insurance leads to lower agricultural chemical use. However, Wu (1999) examining the effect of crop insurance on both cropping and chemical use, found the opposite result. Evidence from Nebraska survey data suggested that crop insurance encouraged farmers to shift from pasture and hay to corn. While fewer chemicals were applied per acre, the shift in acreage toward corn (a relatively chemical intensive crop) had a net effect of increasing chemical use. Recently, research has been extended to consider links between crop insurance conservation tillage adoption, arguing farmers have less incentive to perform self-protection if they are protected by crop insurance. Ding et al. (2009) conclude that insured cropland has significantly less no-till adoption. Schoengold et al. (2015) further take *ad hoc* disaster payment into consideration and find that while both insurance and disaster payments have significantly negative effect on no-till adoption, disaster payments had a larger effect. Most recently, a study by Fleckenstein et al. (2020) focused solely on crop insurance and conservation tillage and cover crop adoption. Their study surveyed farmers about barriers to adoption of these conservation practices. Respondents indicated that crop insurance was not a barrier to practice adoption.

Irrigation Irrigation brings water to farm fields using pipelines and canals from reservoirs or pumps from wells. Agricultural water accounts for around 90% of the water usage in the U.S. Irrigation is a critical practice in U.S. agriculture especially in arid areas. In regions that have sparse rainfall, irrigation is the main method to maintain moisture in the soil. In regions that have irregular rainfall, irrigation helps smooth crop growth. Even in the humid U.S. east, with greater and more regular rainfall, supplemental irrigation can reduce production risk (Dalton et al., 2004). However, irrigation utilization rates vary across the U.S. In 2017, Arizona and California have over 96% of the cropland irrigated, which are the highest in the nation. On the other end, West Virginia has only less than 0.5% of the cropland irrigated.

Literature on the relationship between irrigation and conservation tillage is relatively small. Wade and Claassen (2017) surveyed corn and soybean farmers and discussed the probable substitute relationship between irrigation and no-till. They argued that the residues left without tilling the soil, creating an uneven surface, might be unfriendly to irrigation machinery. They also found that irrigation reduces the possibility of continuous no-till by 9%. Mitchell et al. (2007) surveyed California farmers with 25% of the farmers responding that no-till is not compatible with their irrigation system. They concluded that new irrigation systems are needed to eliminate the burden of no-till. Fuglie (1999) studied conservation tillage and pesticide use. His results showed that irrigation significantly discourage the adoption of no-till. Schoengold et al. (2015) also mentioned the possible role of irrigation in conservation tillage adoption but they did not treat irrigation as an explanatory variable.

CHAPTER 3

Data

In this paper, we are interested in the relationships between conservation tillage, irrigation, crop insurance and tenure status. Data on tillage practice adoption by tenure status come from Table 76 of the 2012 and 2017 editions of the Census of Agriculture[1]. These are the two most recent Census survey years and the only ones to include questions linking tillage practices to tenure status. Table 76 reports the number of acres in each US state practicing conventional tillage, reduced tillage, and no till by tenure status. Farm operations are divided into three groups. Full owners only farm cropland they own. Tenants only farm cropland that they lease in from others. They do not own any of the cropland they operate. Part owners operate a mix of land that they own and land that they lease in from others. In principle, for each tillage practice, there could be up to 300 observations (50 states X 2 years X 3 tenure classes). In practice, though, we had fewer observations because of missing data for Rhode Island, Nevada, New Hampshire, Alaska, and Hawaii. These states were excluded from our analysis.

To obtain information regarding weather, soil quality, etc. that may affect tillage decisions, but which are not included in the Census, we also assembled an auxiliary data set for 2012 and 2017 from a few open data sources: NOAA Climate Data Online[2], Bureau of Reclamation RISE[3], USDA RMA's Summary of Business[4], and USDA ERS Staff Paper No.9527[5]. Due to the restriction of data availability, we are

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[1] Available at `https://www.nass.usda.gov/AgCensus`

[2] Available at `https://www.ncdc.noaa.gov/cdo-web/datasets`

[3] Available at `https://data.usbr.gov/`

[4] Available at `https://prodwebnlb.rma.usda.gov/apps/SummaryOfBusiness`

[5] **Weather and Yield, 1950-94: Relationships, Distributions, and Data.** Lloyd D. Teigen and Milton Thomas, Jr., Commercial Agriculture Division, Economic Research Service, U.S. Department of Agriculture. Staff Paper No.9527.

only able to assemble a state level dataset.

Census of Agriculture The USDA Census of Agriculture provides a comprehensive count of U.S. farms and ranches and the people who operate them. The first Census of Agriculture was conducted by the Census Bureau in 1840 as a part of the United States Census of 1840. In 1997, the responsibility of the Census was shifted to USDA. The Census is conducted once every 5 years with the most recent survey conducted in 2017. Table 76 of the Census[6] entitled ”Summary by Tenure of Farm Operation” is our primary source of data. Although Census provides county level data for some variables, data that are disaggregated by tenure status are only available at the state level. For each tenure group, Table 76 reports land use acreage and percentage, crop choices, numbers and sizes of farms, operator characteristics, sales, conservation practices acreage including tillage practices, and other variables we are interested in such as crop insurance participation and use of irrigation. Operator characteristics data allow us to create a set of control variables, e.g. percentage of producers who are female, average years of experience, etc. Unfortunately, data on the percent acreage land covered by insurance is not available for several states in either 2012 or 2017 which forces us to use percentage of operators insured to measure insurance coverage. We are able to form a tenure-by-state-by-year dataset consists of 270 observations. This is 45 states X 3 tenure classes X 2 years = 270 observations.

NOAA Climate Data Online Although the Census of Agriculture is a comprehensive data set, it only relates to farms, farmers and land use. While a number of factors in the natural environment might affect farmers' production decisions, the Census of Agriculture does not provide this information. NOAA (National Oceanic and Atmospheric Administration) Climate Data Online, also NOAA CDO, is a versatile weather and climate database. It uses land-based stations, remote sensing, radar, etc. to automatically collect and report weather, climate, and drought in-

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[6] See Figure 1.

formation. Drought is measured using a D0 to D4 system. This specific index has 6 levels: from no drought, abnormally dry (D0), moderate drought (D1), severe drought (D2), extreme drought (D3), to exceptional drought (D4). The data provide the percentage of each drought class in county-week level. One might expect adoption of conservation tillage practices to be higher on farms with cropland that is highly erodible land (HEL). This is because the productivity benefits of soil conservation would be higher and also because on environmental restrictions on certain conventional tillage practices on HEL land. Measures of soil erosion, were obtained from the USDA Natural Resources Conservation Service 2012 National Resources Inventory Summary Report (August 2015)[7].Data come from Table 15 - Estimated average annual sheet and rill erosion on non-Federal rural land by State and year. It reports erosion in terms of tons per acre per year at the state level on cultivated cropland.

Climate Data Observations are aggregated up to the state level. This presents challenges especially in very large states with a high degree of climate variation. Climate varies in states like California, for example, Northern California has more moisture whereas Southern California does not. Also there are large potions of the state with little or no agricultural production. So, unweighted average measures of state-level climate may not accurately reflect production conditions farmers face. This applies to many other states, too. For example, the bulk of Arizona's crop production is in arid, low desert areas in the southern portion of the state. But, the northern part of the state is cooler and mountainous. To resolve this potential problem, we turn to climate variables from Teigen and Thomas, Jr. (1995), which weights weather station measurements of temperature and precipitation by harvested cropland. Areas that harvest more crops are assigned heavier weights, which more accurately represent the weather and climate that farmers are facing. Teigen and Thomas, Jr. (1995) report long term averages of precipitation and temperature (weighted by harvested cropland) by state. The variables used in this study include

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[7] Available at `https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd396218.pdf`

length of growing season, average temperature from February to April, and average annual precipitation. The growing season is measured in months and is defined in this study as the number of months the average temperature exceeds 32 degrees Fahrenheit (0 degrees Celsius).

Bureau of Reclamation RISE Irrigation is considered an important part of farmers' risk-reduction toolbox especially in arid regions. The Bureau of Reclamation manages large dams and reservoirs in the western half of the United States. It is also the largest water wholesaler in the country. In the West, where irrigation is more common, dam water delivered by The US Bureau of Reclamation (USBR) accounts for approximately 20% of irrigation water used, usually at federally-subsidized rates. Therefore, states with better access to USBR water are potentially more likely to adopt irrigation. The USBR Reclamation Information Sharing Environment (RISE) database provides the percentage of irrigation water that is sourced from USBR in each state for 2012 and 2017. Note that the data of eastern states that is outside of Bureau of Reclamation operating regions[8]. Data on water supply infrastructure is important for an identification strategy to include irrigation in conservation tillage regression equations. As irrigation and conservation tillage are strategies to combat insufficient soil moisture, irrigation would be an endogenous variable in a conservation tillage equation. To create an instrumental variable that is properly identified, it is necessary to use a variable that affects irrigation choice, but not tillage choice directly. The presence and extent of water supply infrastructure (as captured by USBR water deliveries) would be expected to affect irrigation adoption. But the existence of dams and delivery canals would not be expected to directly affect tillage choice.

USDA RMA's Summary of Business Crop insurance is another essential practices in the risk-reduction toolbox. However, while the Census of Agriculture provides some data on acreage and producers enrolled in federal crop insurance, it

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[8] See Figure 2

does not provide data on the supply and structure of insurance programs. Again, such supply and structure variables would be important for an instrumental variable identification strategy. The cost and other particulars of insurance policies would affect insurance coverage decisions, but they would not be expected to directly affect tillage decision. We turn to USDA Risk Management Agency's Summary of Business database for information on the structure of crop insurance delivery. This database reports annual state-level data on insurance policy level of coverage, premiums, indemnities, and government subsidies for insurance. From these statistics, we are able to construct a payoff ratio variable and a price of coverage variable. The payoff ratio is the ratio of indemnity payments to premiums farmers pay (net of government subsidies). If the payoff ratio is greater than 1, farmers in the state, on average, get more cash in indemnity payment than they pay in insurance premiums. High payoff ratios could be an incentive for purchasing insurance. Note that the only available coverage data in RMA's Summary of Business is percentage of operators being covered by policy rather than acreage. The price variable is the amount of premiums paid divided by the total liability (coverage) obtained. A lower price means that farmers have more coverage per dollar spent.

Fuel Price Traditional tillage requires more machine passes through farm fields and so, means higher fuel costs. One might expect that higher fuel prices would discourage conventional tillage and encourage conservation tillage. We scrape fuel price data directly from The Department of Energy's Energy Information Administration (EIA) website[9]. We use lagged state average gasoline price (i.e. 2011 annual average gasoline price measured in inflation adjusted dollars per BTU for 2012 data.) as a proxy for cost of tillage.

Table 1 and 3 provide summary statistics and a description of variables used in the study. Note that all variables not from Census are tenure-invariant but state-variant. Table 2 provide a summary of tenure-variant variables.

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[9] Find data at `https://www.eia.gov/state/seds`

CHAPTER 4

Econometrics Analysis

To investigate the relationship between tenure status and conservation tillage, we proceed by regressing conservation tillage adoption rate variables on land tenure dummy variables and a variety of control variables. Let A_{no} be acreage practicing no till among a particular tenure class in a state in a given year. Also, A_{red} is acreage practicing reduced tillage, and A_{cnv} is acreage practicing conventional tillage. The variable S_{no} is the proportion of acreage practicing no till, so $S_{no} = A_{no} / (A_{no} + A_{red} + A_{cnv})$. Likewise A_{red} is the proportion of acreage practicing reduced till, so $S_{red} = A_{red} / (A_{no} + A_{red} + A_{cnv})$ and S_{cnv} is the proportion of acreage practicing conventional tillage, so $S_{cnv}= A_{cnv} / (A_{no} + A_{red} + A_{cnv})$. Previous research has measured aggregate adoption of tillage as a logistic function (Ding et al. (2009) and Schoengold et al. (2015)). We will follow this convention so that one dependent variable in regression analysis is Red $= \ln(S_{red} / S_{cnv})$, while the second is NoTill $= \ln(S_{no}/S_{cnv})$. So, each dependent variable measures conservation tillage adoption relative conventional tillage. The basic regression equations are:

$$\text{Red}_{it} = c + \gamma \text{Part}_i + \alpha \text{Tenant}_i + \sum_{k=3}^{k} \beta_k X_{it} + \lambda_i + \tau_t + \epsilon_{it}$$

$$\text{NoTill}_{it} = c + \gamma \text{Part}_i + \alpha \text{Tenant}_i + \sum_{k=3}^{k} \beta_k X_{it} + \lambda_i + \tau_t + \epsilon_{it}$$

The dummy variable Part_i takes on a value of 1 if the land is operated by part owners and is 0 otherwise. Similarly, Tenant_i takes on a value of 1 if the land is operated by full tenants and is 0 otherwise. Full owners are the default category so the tenure dummy variables capture effects of deviations from full owners. In addition to tenure variables, there are a variety of control variables X_{kit} which consist of rainfall, temperature, erosion, length of growing season, availability of soil moisture, fuel price, the percentage of female producers in each state-tenure-year triplet and the average number of years each producers farmed their current operation in each state-tenure-year triplet. The variable Insur_{it} is the percentage of farm operations that have crop insurance, while Irrig_{it} is the percentage of cropland in each triplet that is irrigated. Finally λ_i and τ_t are region and time fixed effects. The time effects simply indicate whether observations are from the 2012 or the 2017 Census of Agriculture. For region-specific fixed effects, We use USDA farm production regions. See Figure 4 for details.

4.1 Land Tenure and Tillage

Different land tenure types have different tillage adoption patterns. Figure 3 illustrates the average tillage adoption by tenure type, based on Census of Agriculture data from 2012 and 2017. From these very aggregate data, there does not appear to be very strong evidence that full owners are more likely to adopt conventional tillage than renters. Both tenants and part owners have higher rates of reduced tillage adoption than full owners. Part owners have a higher rate of adoption of no-till than full owners. Compared to part owners, both tenants and full owners have higher rates of adoption of conventional tillage.

Tillage adoption patterns vary significantly across the country. Take no-till as an example, Figure 6(2012) and Figure 5(2017) map the percentage of acreage under no-till practice in 2012 and 2017. Deep red indicates higher adoption rates. States in the southwest portion of the United States (Texas, New Mexico, Arizona, Nevada, Utah, and California) have very low no-till adoption rates. Northern Plain states including Iowa, Nebraska, North and South Dakota have medium to high no-till adoption. Montana and many eastern states such as Virginia, Maryland, and Tennessee have the highest no-till adoption rate in the nation. These patterns suggest that the conservation tillage decisions vary not only by tenure class but also across time and locations.

Table 4 reports ordinary least squares (OLS) estimation results of a simple model of conservation tillage practice adoption. The model includes first only the tenure variables, then incrementally adds production region and year fixed effects. For this preliminary regression, no other control variables are included. For both reduced-till and no-till adoption, the region and time fixed effects are jointly significant at the one-percent level. The null hypothesis that tenure status has no effect on tillage choice could not be rejected for no-till. For reduced-tillage, however, the joint hypothesis that both tenure variables have no effect on adoption is rejected at the 5-percent level. In terms of individual significance, the Tenant coefficient is positive and significant at the 5-percent level, while the Part Owner coefficient is positive and significant at the 10-percent level. These results are not consistent with the argument that owning cropland has a positive effect on conservation tillage adoption. They do, though, omit several control variables. The tenure variables explain very little of the overall variation in the data. The results suggest that time and regional fixed effects are important. Including these variables greatly increases model R-squared, especially for the no-till equation. Adding the fixed effects has virtually no effect on the size and significance of the tenure coefficients.

4.2 Other Risk Management Practices

We next consider irrigation and insurance as risk management practices. We want to look into how these variables affect conservation tillage adoption. Because irrigation and insurance both affect farm production risk, including these variables in the conservation tillage regressions may introduce simultaneity bias. This is because adoption of irrigation, purchasing crop insurance and adopting conservation tillage practices might all be decided together. The next set of regressions considers factors affecting Insur_{it} (the percentage of farm operations that have crop insurance) and Irrig_{it} (the percentage of cropland in each triplet that is irrigated). These regression results can be used to later include insurance and irrigation patterns in the conservation tillage equations, using an IV approach to correct for simultaneity. The regression equations are as follows.

$$\text{Ins}_{it} = c + \gamma\text{Full}_i + \alpha\text{Ten}_i + \beta_1\text{Price}_{it} + \beta_2\text{Payoff}_{it} + \sum_{k=3}^{N}\beta_k X_{it} + \lambda_i + \tau_t + \epsilon_{it}$$

$$\text{Irr}_{it} = c + \gamma\text{Full}_i + \alpha\text{Ten}_i + \beta_1\text{USBR}_{it} + \sum_{k=2}^{N}\beta_k X_{it} + \lambda_i + \tau_t + \epsilon_{it}$$

where X_{it} are a set of common control variables, while λ_i and τ_t are region and time fixed effects. The variable Price_{it} is crop insurance premiums paid in a state divided by the total amount of coverage provided by insurance policies. This represents the cost of obtaining a given amount of coverage. The variable Payoff equals the total indemnity payments divided by farmer-paid premiums. The variable USBR_{it} measures the share of irrigation water in a state that is supplied by USBR. Control variables used in the irrigation and insurance regressions included long-run average temperature, long-run precipitation, soil erosion, the percent of producers who are female in each state-tenure-year triplet and the average years operating the current farm in each triplet. In addition, the variable Moisture is a measure of lack of drought. It is percentage of acres in a state not experiencing D0 to D4 drought, averaged over the previous five years.

Table 5 reports on the irrigation and insurance regressions with and without fixed effects. Rainfall is negatively associated with the share of acres irrigated and with the share of farms with crop insurance. This suggests that uptake of both irrigation and insurance is higher in more arid states. Irrigation adoption is also higher in states with higher average temperatures. The soil erosion variable is negatively associated with irrigation adoption. The soil erosion variable is based on the universal soil loss equation (Wischmeier and Smith, 1978). In the formula for this equation, variables that contribute to greater erosion, such prevalence of soils with low water holding capacity or fields with greater slopes, also are associated with poor irrigation performance. Irrigation adoption is positively associated with triplets with a higher share of female producers. But, irrigation is negatively associated with triplets where producers have farmed more years on their current operations. Fixed region and time effects are significant in the irrigation equation. Participation in crop insurance is greater among triplets with a lower share of female producers but where average experience on the current farm is greater. Fixed effects are significant in the insurance equations as well. Also, in the insurance equation the coefficients on the insurance market structure variables did not have the expected signs. For example, the sign on for the payoff ratio (the ratio of indemnity payments to premiums farmers pay) is negative (though insignificant in some equations. The price variable is the amount of premiums paid divided by the total liability (coverage) obtained. A lower price means that farmers have more coverage per dollar spent. Yet, the coefficient for this variable was positive.

Results suggest that part owners adopt irrigation and purchase crop insurance more than full owners. The tenant variable is significant and positive for crop insurance, but insignificant for irrigation, once fixed effects are included.

4.3 IV Estimation of Tillage Equations

Table 6 reports on conservation tillage adoption equations that now include control variables as well as potentially endogenous variables for irrigation and insurance uptake. The soil moisture variable measuring the share of area without drought was positive and significant for no till adoption and insignificant for reduced tillage. This runs somewhat counter to the argument that conservation tillage adoption is a response to low soil moisture. The long-run average rainfall variable is positively associated with no till, but negatively associated with reduced tillage adoption. Irrigation adoption has a strong negative affect on adoption of both no till and reduced tillage, suggesting that these are substitute strategies for managing production risk. A longer growing season is positively associated with conservation tillage adoption. Insurance is positively associated with no till adoption (in the equation that includes time and region fixed effects). Adoption of reduced tillage is positively associated with states with greater soil erosion. The erosion variable was positive but insignificant for no till. Fuel prices had an unexpected negative sign, but this effect was either insignificant or reversed when fixed effects were included.

4.4 System of Equation

Chances are that tillage, irrigation, and insurance enrollment are simultaneously decided (Wu and Babcock, 1998; Ding et al., 2009; Schoengold et al., 2015; Roberts et al., 2006). In fact, farmers have to plan risk management practices before they start a new season and can hardly change them during the season. Because conservation tillage, irrigation, and crop insurance are major risk management practices, we suggest they may substitute for each other. On the other hand, it is possible that farmers use multiple strategies to achieve greater risk reduction (Wu and Babcock, 1998). Figure 7 plots the irrigated cropland in 2012 using Census of Agriculture data. Irrigated cropland is concentrated in the Pacific region and arid Southwest, the Mississippi Delta, and Nebraska. Florida also has a decent amount of acres of irrigated land. In contrast, in the no-till maps (Figures 5 and 6), California, Idaho, Southwestern states, and the Delta are all among the lightest red, which means the lowest adoption rates for no-till. Another noteworthy region in these two maps is the Southeast. Alabama, Tennessee, South Carolina are poorly irrigated but have a high no-till adoption rate. In contrast, their adjacent states, Georgia, Mississippi and Florida, have more irrigation, but considerably lower no-till adoption rates .To test the relationship between tillage, irrigation, and insurance, and how tenure status play a role on the decision-making process, we move on to a simultaneous equation system that allows error term to be correlated.

$$\begin{aligned}
\mathrm{NoT}_{it} &= c + \gamma \mathrm{Full}_i + \alpha \mathrm{Ten}_i + \beta_1 \mathrm{Irr}_{it} + \beta_2 \mathrm{Ins}_{it} \\
&\quad + \sum_{k=5}^{k} \beta_k X_{it} + \lambda_i + \tau_t + \epsilon_{it} \\
\mathrm{Red}_{it} &= c + \gamma \mathrm{Full}_i + \alpha \mathrm{Ten}_i + \beta_1 \mathrm{Irr}_{it} + \beta_2 \mathrm{Ins}_{it} \\
&\quad + \sum_{k=4}^{k} \beta_k X_{it} + \lambda_i + \tau_t + \epsilon_{it} \\
\mathrm{Ins}_{it} &= c + \gamma \mathrm{Full}_i + \alpha \mathrm{Ten}_i + \beta_1 \mathrm{Irr}_{it} + \beta_2 \mathrm{NoT}_{it} + \beta_3 \mathrm{Red}_{it} + \beta_4 \mathrm{Price}_{it} + \beta_5 \mathrm{Payoff}_{it} \\
&\quad + \sum_{k=6}^{k} \beta_k X_{it} + \lambda_i + \tau_t + \epsilon_{it} \\
\mathrm{Irr}_{it} &= c + \gamma \mathrm{Full}_i + \alpha \mathrm{Ten}_i + \beta_1 \mathrm{Ins}_{it} + \beta_2 \mathrm{NoT}_{it} + \beta_3 \mathrm{Red}_{it} + \beta_4 \mathrm{USBR}_{it} \\
&\quad + \sum_{k=5}^{k} \beta_k X_{it} + \lambda_i + \tau_t + \epsilon_{it}
\end{aligned}$$

where fuel_{it} is the instrument for no-till in equation (4.3) (4.4), Price_{it} and Payoff_{it} are the instruments for Insurance in equation (4.1) (4.2) (4.4), USBR_{it} is the instrument for Irrigation in equation (4.1) (4.2) (4.3).

Before we can proceed to estimate the system, We discuss the validity of each instrumental variables below.

USBR As one of the largest water wholesalers in the western U.S. the USBR is responsible for managing dams and reservoirs and supplies of irrigation water throughout the West. The USBR RISE data center also collects data on how the water sold by the bureau accounts for each states agriculture water usage. The variable USBR documents the percentage of irrigation water that is sourced from the Bureau. USBR is a large supplier on irrigation water in the West, for example, USBR water accounts for 26% of the irrigation water used in Idaho which has around 65% acres irrigated, while it has no business conducted in the East (USBR variable in the states out of its operation regions are zero. In comparison, USBR only provided 0.3% of the irrigation water, in North Dakota in 2012, which irrigated less than 1%

of its cropland. Second, USBR has the property of exclusion. USBR does not affect conservation tillage and insurance decisions directly. It would ultimately affect each system's dependent variable through the irrigation variable.

Payoff Ratio and Price USDA RMA records detailed crop insurance information in their database. We are able to find insurance price and payoff ratio that might affect insurance decisions that don't affect tillage or irrigation decisions directly. Price is simply the premium per thousand dollar worth crop covered in policy. The Payoff Ratio is defined as the ratio of indemnity payments to insurance premiums (net of subsidies). We use five year average Payoff Ratio and Price (i.e. 2007-2011 average for 2012). In the U.S., crop insurance is heavily subsidised. Therefore the amount paid for the policy is the original premium minus the portion paid by the government. The Payoff Ratio and Price variables are both relevant to insurance. When farmers have the information on previous indemnities, that may inform their expectations about future indemnity payments. Basic economic theory also tells us that the demand curve for insurance is downward sloped, hence a lower price is associated with higher quantity. The Payoff Ratio and Price variables are both exclusive. They would be expected to alter insurance decisions but not tillage or irrigation decisions through a direct channel.

Fuel Apart from the risk reduction and environment protection function, conservation tillage requires less machinery usage which leads to less fuel consumption. For years USDA and state agriculture extension services list cost saving as a major benefit for reducing tillage intensity. There is no obvious link between fuel prices and insurance enrollment. One could argue that fuel prices could affect irrigation pumping costs. But, much of the energy provided for irrigation pumping comes from electricity, not liquid fuel.

4.5 Empirical Results

Table 7 provides the results from 3SLS (three stage least squares) estimation with and without both fixed effects. We will mainly look at column (2)(4)(6)(8) which have fixed effects included in the equations.

Tenure The coefficient for Part Owners is negative and significant in the no till equation, but not significant in the reduced tillage equation. The Tenant variable was insignificant in both the reduced tillage and no till equations. The Tenant variable was positively associated with higher rates of crop insurance enrollment.

Climate and Drought We find no till adoption was positively associated with greater average rainfall, a longer growing season and greater soil moisture. Adoption of reduced tillage was negatively associated with greater rainfall, but positively associated with a longer grower season.

Irrigation Higher rates of irrigation adoption were associated with strong, negative effects on both no till and reduced tillage adoption. This suggests that, to the extent that conservation tillage is a response to dry conditions, conservation tillage and irrigation seem to be substitute strategies. Recent drought (as measured by the Moisture variable) does not appear to spur higher rates of irrigation use. While irrigation adoption has a negative effect on reduced tillage adoption, reduced tillage also appears to have a negative effect on irrigation adoption. This suggests the effects are self-reinforcing.

Erosion Adoption rates for reduced tillage appear to be higher in states with greater soil erosion.

Producer Characteristics In triplets with a greater share of female producers, reduced tillage adoption and crop insurance participation rates are lower. In triplets where producers have greater experience on their current farms, insurance enrollment rates are higher.

Instruments The results suggest that more research is needed to identify strong instruments for a three-stage-least-squares estimation approach. The fuel price variable (an instrument for the tillage equations) was not statistically significant. The instruments in the insurance equation did not have the signs expected by economic theory.

Crop Insurance Crop insurance not only had no effects on other practices, but also did not appear to be significantly affected by the other variables. This perhaps suggests that in future research, the specification might be treated as recursive, with crop insurance treated as a predetermined exogenous variable. Results here do not suggest that insurance discourages conservation tillage adoption. This is consistent with the findings of Fleckenstein et al. (2020) where growers reported that insurance was not a barrier to adoption.

4.6 Some Thoughts

Our results are limited because that data are of very aggregate nature. There are limits to the inferences one can make with state-level data. Although groups were separated by tenure status, in other ways the data were very aggregated. Future research using farm-level data, such as (Shaban, 1987) may do a better job at isolating effects of tenure status.

Our framework hypothesizes that farmers choose from four risk management practices in growing season. Figure 8 illustrates the more precise relationship inside risk management practices. A nested discrete choice model allowing farmers to choose multiple options may be suitable for this kind of problems and be applied to farm level data. Farmers can only apply reduced or no-till on any given acre. It is possible, though for farmers to practice one type of conservation tillage on one part of their land and another type on other parts of their land.

As noted above, a number of the instrumental variables that we chose for this analysis were weak. An exception was the instrument for the irrigation equation. Future research could seek to apply stronger instruments in the tillage and insurance equations. A notable variable excluded from the in the models is farm size. This was considered a driving force towards the Dust Bowl (Hansen and Libecap, 2004). Farm size has also been a significant variable in studies of adoption of irrigation and conservation tillage.

Finally, the data divide farms into three three tenure classes. Our result show somewhat weak evidence that some renters (partial owners) have lower adoption rates of some conservation tillage practices (no till). This division of farms, though, says nothing about the type of rental contract. We do not know if the contracts are short-term or long-term. A tenant under a long-term contract may be more likely to treat rented land as their own and adopt land productivity enhancing practices. Table 2 shows, that at this very aggregate level of data, partial owners and tenants appear to have been farming their rented land for many years. So, perhaps they do treat rented land as their own.

CHAPTER 5

Conclusion

This study examines the the relationships between land tenure and farm risk management practices. To our knowledge, the paper is the first to investigate such a question on a national scale and to treat three risk management practices (conservation tillage, irrigation, and crop insurance) as jointly determined in a system of equations. The goal of this study is to test the effect of tenure on adoption on three risk reduction practices: conservation tillage, irrigation, and crop insurance. Univariate analysis found no negative affect of land leasing on conservation tillage adoption. In multiple regression analysis, however, there was evidence that part ownership was negatively associated with adoption of no till. No difference in adoption between full owners and full tenants was found.

Irrigation adoption was greater in triplets in states with lower average annual precipitation, longer growing seasons, and warmer planting seasons. Irrigation adoption rates were lower in states with greater soil erosion. Some factors that contribute to greater soil erosion, such as steeper slopes or soils with lower water holding capacity, also contribute to poorer irrigation performance. Experiencing drought over the previous five years was not found to increase state-level adoption of irrigation.

Past findings on the relationship between crop insurance and adoption of conservation tillage have been mixed. Some studies have found a negative association between the two, while other research suggests that crop insurance is not a barrier to conservation tillage adoption. We found no statistically significant association between crop insurance enrollment and conservation tillage adoption rates.

Adoption of both reduced tillage and no till were lower in states with higher irrigation adoption rates. Controlling for other factors, this negative relationship was strong and statistically significant. This suggests that irrigation and conservation tillage might be substitute strategies for adapting to low soil moisture production conditions.

This study applied instrumental variable and simultaneous equation methods to account for the possibility of the endogeneity of tillage, insurance, and irrigation choice. For the different practice adoption (and enrollment) equations, results were sensitive to model specification (e.g. between reduced form least squares, two-stage instrumental variable, and three stage least squares methods). Also, it was found that the instruments used in the present study were weak instruments. Future simultaneous equation modeling would benefit from identification and use of stronger instruments. We also argue that future research should focus on micro-level data and incorporate additional relevant variables, such as farm size and length of lease contracts.

Figure 1: A sample page of Census of Ag Table 76

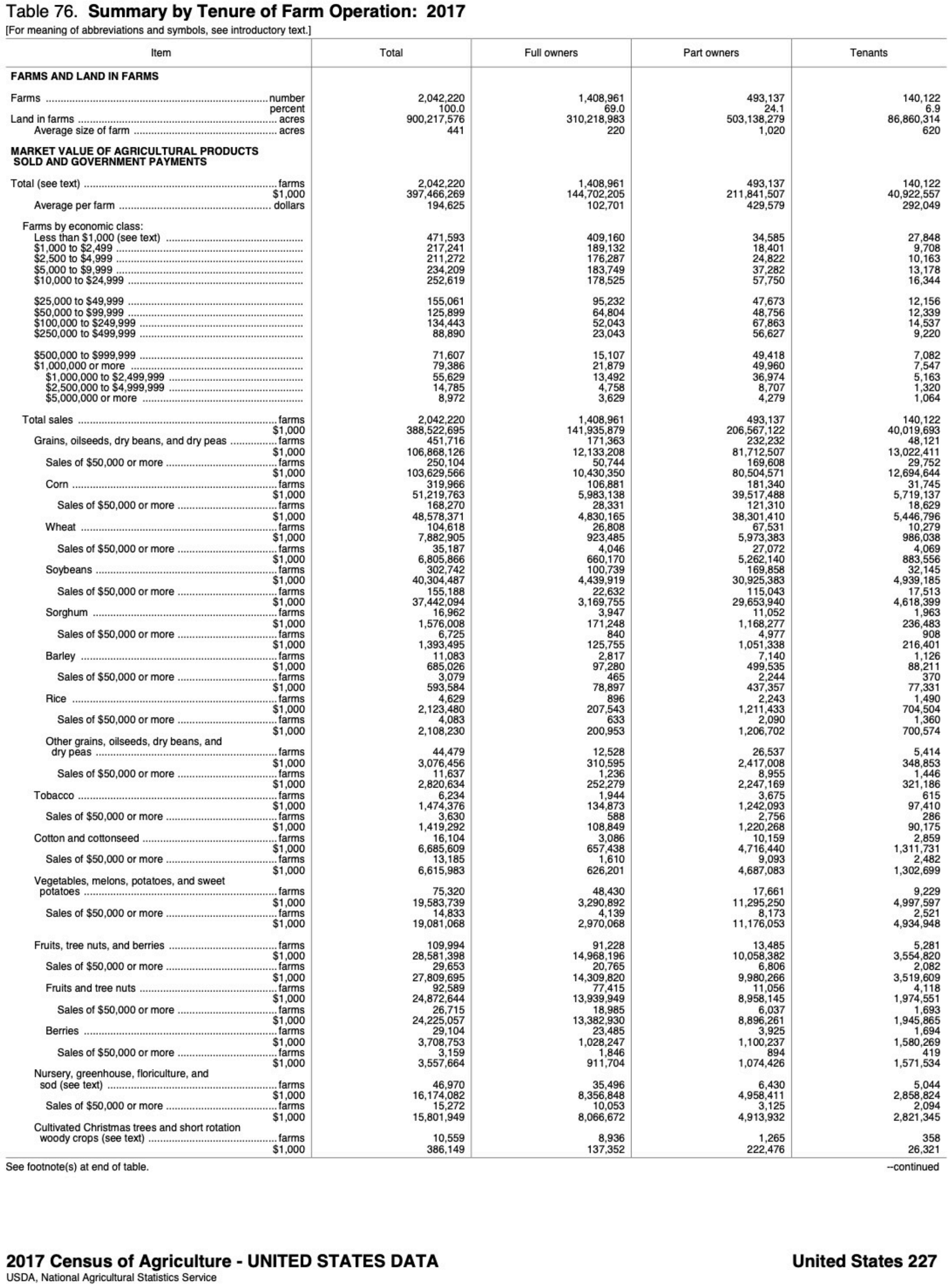

Table 76. **Summary by Tenure of Farm Operation: 2017**

[For meaning of abbreviations and symbols, see introductory text.]

Item		Total	Full owners	Part owners	Tenants
FARMS AND LAND IN FARMS					
Farms	number	2,042,220	1,408,961	493,137	140,122
	percent	100.0	69.0	24.1	6.9
Land in farms	acres	900,217,576	310,218,983	503,138,279	86,860,314
Average size of farm	acres	441	220	1,020	620
MARKET VALUE OF AGRICULTURAL PRODUCTS SOLD AND GOVERNMENT PAYMENTS					
Total (see text)	farms	2,042,220	1,408,961	493,137	140,122
	$1,000	397,466,269	144,702,205	211,841,507	40,922,557
Average per farm	dollars	194,625	102,701	429,579	292,049
Farms by economic class:					
Less than $1,000 (see text)		471,593	409,160	34,585	27,848
$1,000 to $2,499		217,241	189,132	18,401	9,708
$2,500 to $4,999		211,272	176,287	24,822	10,163
$5,000 to $9,999		234,209	183,749	37,282	13,178
$10,000 to $24,999		252,619	178,525	57,750	16,344
$25,000 to $49,999		155,061	95,232	47,673	12,156
$50,000 to $99,999		125,899	64,804	48,756	12,339
$100,000 to $249,999		134,443	52,043	67,863	14,537
$250,000 to $499,999		88,890	23,043	56,627	9,220
$500,000 to $999,999		71,607	15,107	49,418	7,082
$1,000,000 or more		79,386	21,879	49,960	7,547
$1,000,000 to $2,499,999		55,629	13,492	36,974	5,163
$2,500,000 to $4,999,999		14,785	4,758	8,707	1,320
$5,000,000 or more		8,972	3,629	4,279	1,064
Total sales	farms	2,042,220	1,408,961	493,137	140,122
	$1,000	388,522,695	141,935,879	206,567,122	40,019,693
Grains, oilseeds, dry beans, and dry peas	farms	451,716	171,363	232,232	48,121
	$1,000	106,868,126	12,133,208	81,712,507	13,022,411
Sales of $50,000 or more	farms	250,104	50,744	169,608	29,752
	$1,000	103,629,566	10,430,350	80,504,571	12,694,644
Corn	farms	319,966	106,881	181,340	31,745
	$1,000	51,219,763	5,983,138	39,517,488	5,719,137
Sales of $50,000 or more	farms	168,270	28,331	121,310	18,629
	$1,000	48,578,371	4,830,165	38,301,410	5,446,796
Wheat	farms	104,618	26,808	67,531	10,279
	$1,000	7,882,905	923,485	5,973,383	986,038
Sales of $50,000 or more	farms	35,187	4,046	27,072	4,069
	$1,000	6,805,866	660,170	5,262,140	883,556
Soybeans	farms	302,742	100,739	169,858	32,145
	$1,000	40,304,487	4,439,919	30,925,383	4,939,185
Sales of $50,000 or more	farms	155,188	22,632	115,043	17,513
	$1,000	37,442,094	3,169,755	29,653,940	4,618,399
Sorghum	farms	16,962	3,947	11,052	1,963
	$1,000	1,576,008	171,248	1,168,277	236,483
Sales of $50,000 or more	farms	6,725	840	4,977	908
	$1,000	1,393,495	125,755	1,051,338	216,401
Barley	farms	11,083	2,817	7,140	1,126
	$1,000	685,026	97,280	499,535	88,211
Sales of $50,000 or more	farms	3,079	465	2,244	370
	$1,000	593,584	78,897	437,357	77,331
Rice	farms	4,629	896	2,243	1,490
	$1,000	2,123,480	207,543	1,211,433	704,504
Sales of $50,000 or more	farms	4,083	633	2,090	1,360
	$1,000	2,108,230	200,953	1,206,702	700,574
Other grains, oilseeds, dry beans, and dry peas	farms	44,479	12,528	26,537	5,414
	$1,000	3,076,456	310,595	2,417,008	348,853
Sales of $50,000 or more	farms	11,637	1,236	8,955	1,446
	$1,000	2,820,634	252,279	2,247,169	321,186
Tobacco	farms	6,234	1,944	3,675	615
	$1,000	1,474,376	134,873	1,242,093	97,410
Sales of $50,000 or more	farms	3,630	588	2,756	286
	$1,000	1,419,292	108,849	1,220,268	90,175
Cotton and cottonseed	farms	16,104	3,086	10,159	2,859
	$1,000	6,685,609	657,438	4,716,440	1,311,731
Sales of $50,000 or more	farms	13,185	1,610	9,093	2,482
	$1,000	6,615,983	626,201	4,687,083	1,302,699
Vegetables, melons, potatoes, and sweet potatoes	farms	75,320	48,430	17,661	9,229
	$1,000	19,583,739	3,290,892	11,295,250	4,997,597
Sales of $50,000 or more	farms	14,833	4,139	8,173	2,521
	$1,000	19,081,068	2,970,068	11,176,053	4,934,948
Fruits, tree nuts, and berries	farms	109,994	91,228	13,485	5,281
	$1,000	28,581,398	14,968,196	10,058,382	3,554,820
Sales of $50,000 or more	farms	29,653	20,765	6,806	2,082
	$1,000	27,809,695	14,309,820	9,980,266	3,519,609
Fruits and tree nuts	farms	92,589	77,415	11,056	4,118
	$1,000	24,872,644	13,939,949	8,958,145	1,974,551
Sales of $50,000 or more	farms	26,715	18,985	6,037	1,693
	$1,000	24,225,057	13,382,930	8,896,261	1,945,865
Berries	farms	29,104	23,485	3,925	1,694
	$1,000	3,708,753	1,028,247	1,100,237	1,580,269
Sales of $50,000 or more	farms	3,159	1,846	894	419
	$1,000	3,557,664	911,704	1,074,426	1,571,534
Nursery, greenhouse, floriculture, and sod (see text)	farms	46,970	35,496	6,430	5,044
	$1,000	16,174,082	8,356,848	4,958,411	2,858,824
Sales of $50,000 or more	farms	15,272	10,053	3,125	2,094
	$1,000	15,801,949	8,066,672	4,913,932	2,821,345
Cultivated Christmas trees and short rotation woody crops (see text)	farms	10,559	8,936	1,265	358
	$1,000	386,149	137,352	222,476	26,321

See footnote(s) at end of table.

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2017 Census of Agriculture - UNITED STATES DATA **United States 227**

USDA, National Agricultural Statistics Service

Figure 2: US Bureau of Reclamation Operation Region

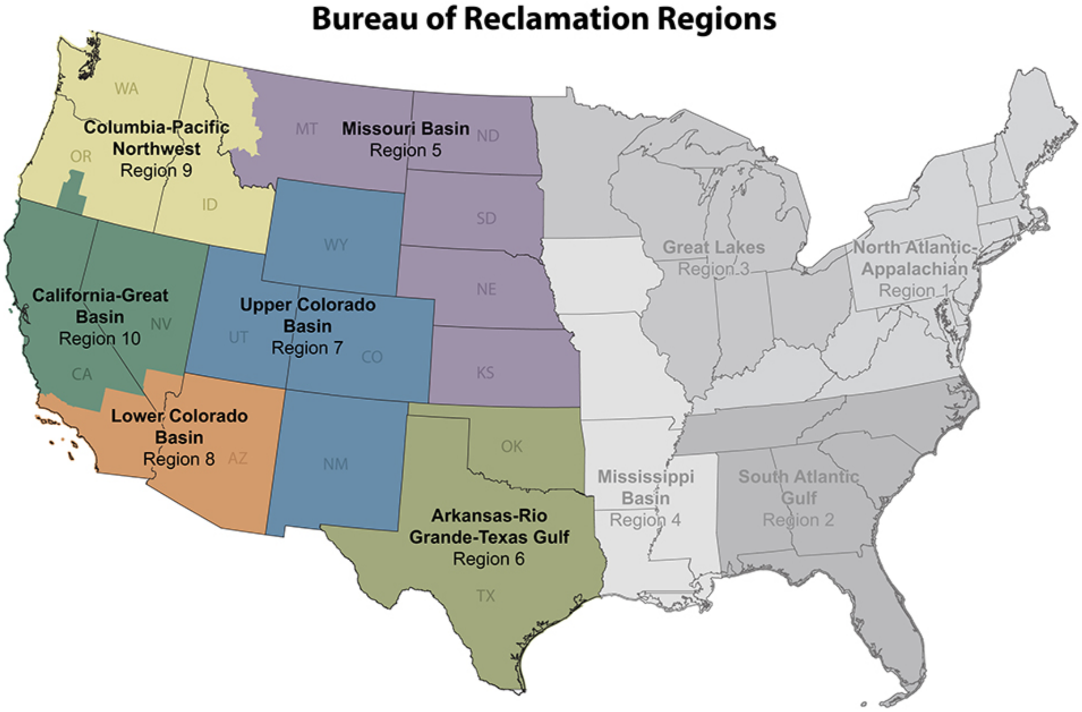
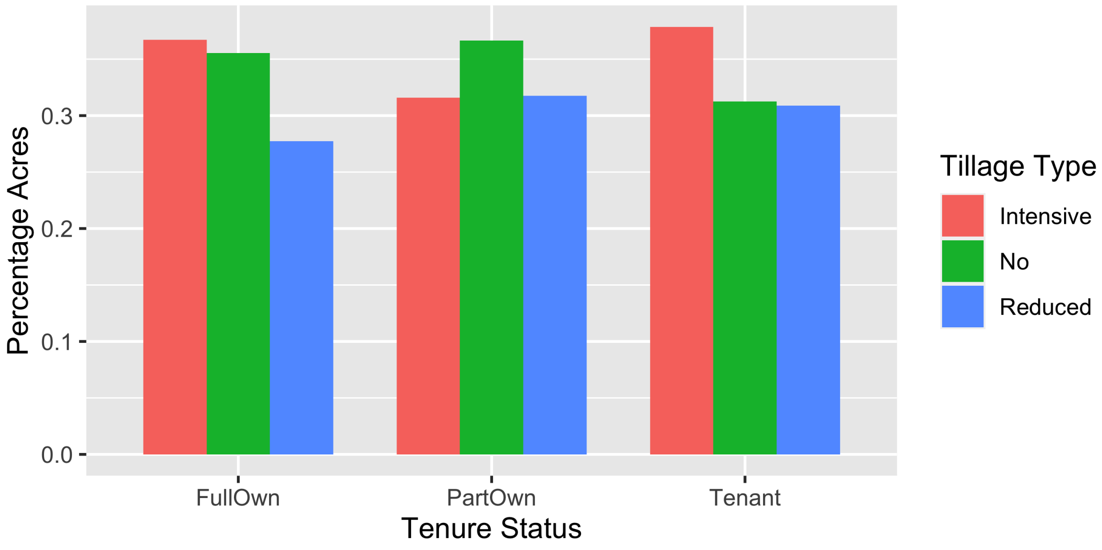


Figure 3: Average Tillage Adoption by Tenure



Note: year 2012 and 2017 aggregated.

Figure 4: USDA Production Region

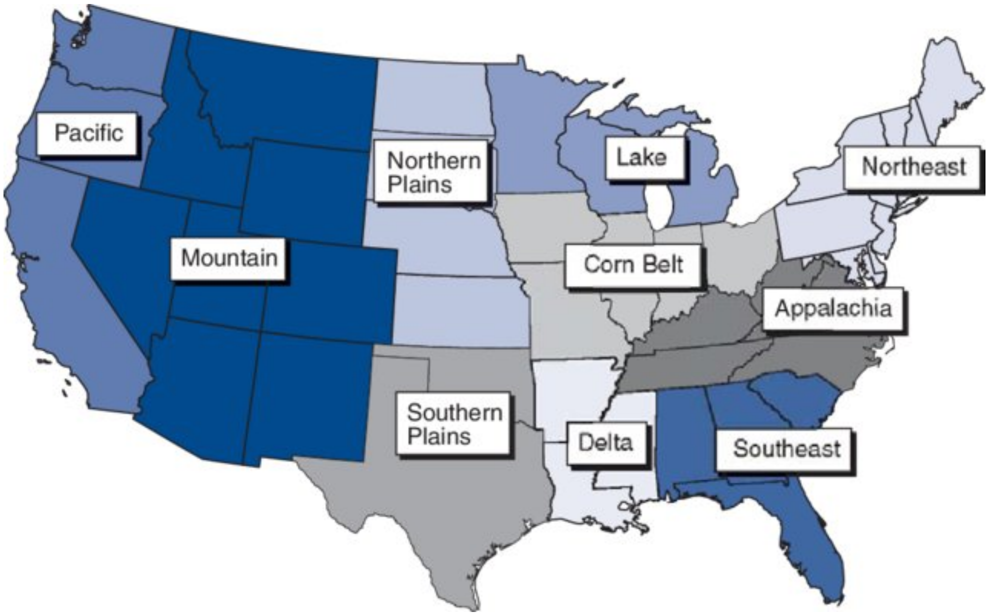
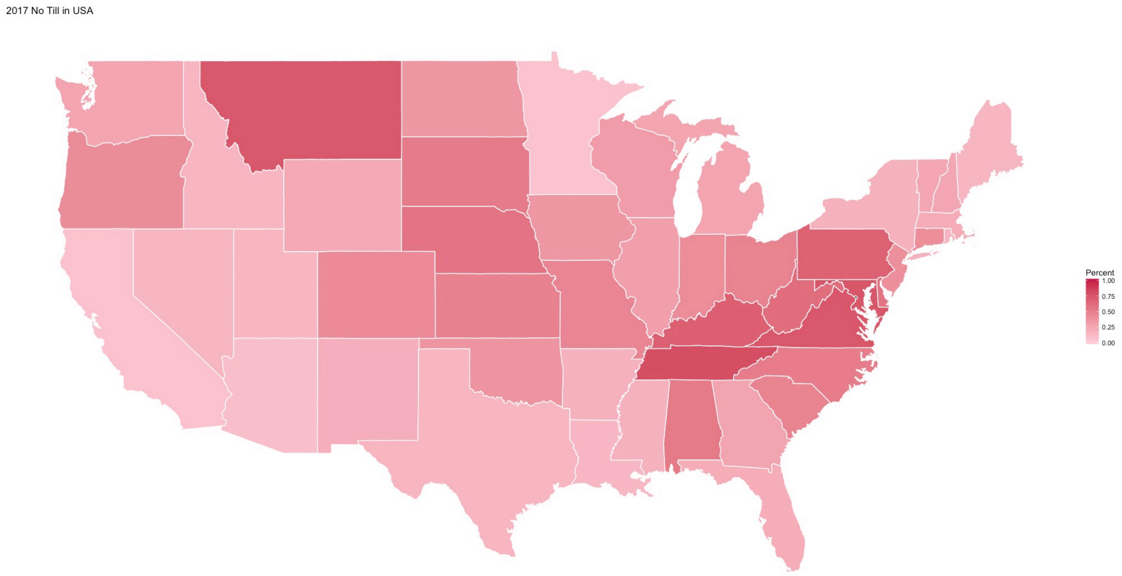
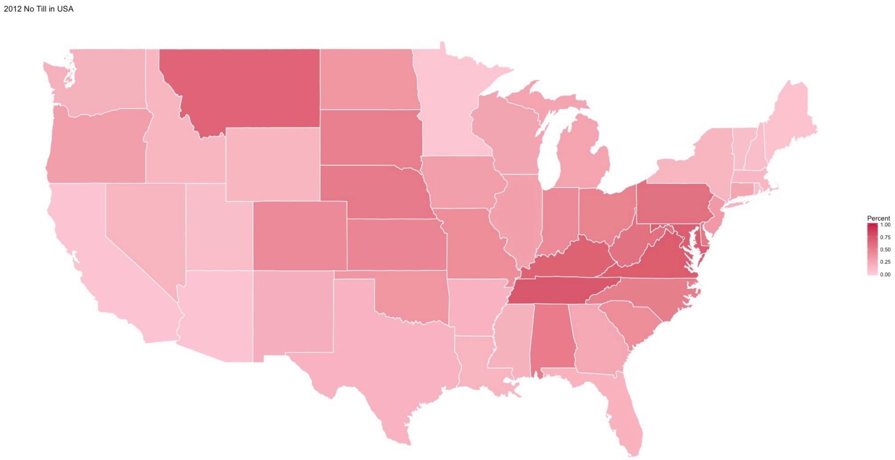


Figure 5: 2017 No Till Adoption Map



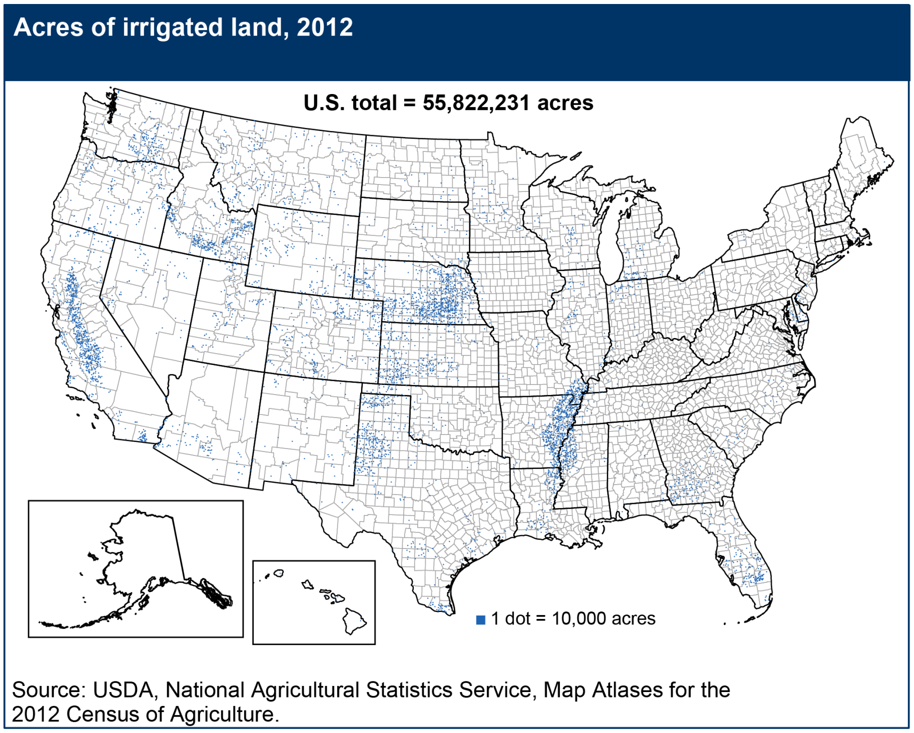
Note: measured in percent of acres.

Figure 6: 2012 No Till Adoption Map



Note: measured in percent of acres.

Figure 7: 2012 Irrigation Map



Source: USDA, National Agricultural Statistics Service, Map Atlases for the 2012 Census of Agriculture.

Figure 8: Tree

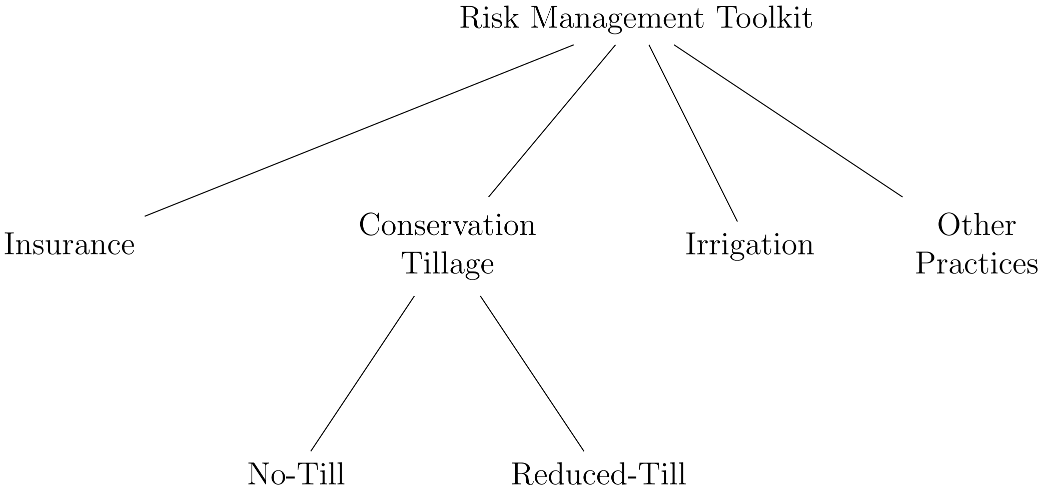


Table 1: Summary Statistics

Statistic	N	Mean	Median	St. Dev.	Max	Min
Acres: %Irrigated	270	0.249	0.110	0.283	0.972	0.001
Operators: %Insured	270	0.228	0.172	0.202	0.856	0.006
Acres: %No Till	270	0.345	0.315	0.204	0.937	0.020
Acres: %Reduced Till	270	0.258	0.256	0.096	0.508	0.016
Precipitation	270	35.224	38.800	13.645	57.400	10.100
Soil Erosion	270	2.588	2.900	1.90	6.062	0.450
Temperature	270	42.876	41.667	9.479	65.500	26.533
Moisture	270	0.612	0.630	0.200	0.964	0.047
Gas Price	270	3.097	3.169	0.281	3.438	2.734
Grow Season	270	10.222	11	1.753	12	7
Gender	270	0.313	0.309	0.074	0.525	0.137
Experience	270	20.923	21.700	4.339	30.400	11.200
Water: %USBR	270	0.032	0	0.060	0.262	0
Insurance: Loss Ratio	270	0.818	0.776	0.275	1.488	0.266
Insurance: Price	270	31.820	29.294	18.035	160.678	12.725
Insurance: Payoff Ratio	270	2.497	2.015	1.997	10.549	0.241

Table 2: Summary Statistics by Tenure

Statistic	N	Mean	Median	St. Dev.	Max	Min
			Full Owner			
Acres: %Irrigated	90	0.242	0.093	0.288	0.972	0.003
Operators: %Insured	90	0.079	0.050	0.073	0.311	0.006
Acres: %No Till	90	0.339	0.316	0.181	0.765	0.035
Acres: %Reduced Till	90	0.240	0.231	0.092	0.498	0.032
%Female	90	0.371	0.370	0.045	0.467	0.278
Experience	90	23.389	23.350	1.880	28.400	19.500
			Part Owner			
Acres: %Irrigated	90	0.236	0.101	0.274	0.967	0.001
Operators: %Insured	90	0.331	0.254	0.215	0.856	0.042
Acres: %No Till	90	0.350	0.316	0.206	0.797	0.044
Acres: %Reduced Till	90	0.271	0.270	0.086	0.451	0.107
%Female	90	0.283	0.280	0.054	0.442	0.164
Experience	90	27.339	27.250	2.017	32.200	22.900
			Tenants			
Acres: %Irrigated	90	0.270	0.134	0.290	0.957	0.003
Operators: %Insured	90	0.274	0.256	0.193	0.760	0.014
Acres: %No Till	90	0.346	0.313	0.226	0.937	0.020
Acres: %Reduced Till	90	0.265	0.264	0.106	0.508	0.016
%Female	90	0.286	0.273	0.081	0.525	0.137
Experience	90	18.944	18.750	2.866	29.700	13.600

Note: Tenure-invariant variables omitted.

Table 3: Variable Used in the Study

Variable	Description
Acres: %Irrigated	Percentage of land irrigated.
Operators: %Insured	Percentage of operators covered by insurance.
Acres: %No Till	Percentage of acres using no-till practices.
Acres: %Reduced Till	Percentage of acres using reduced-till practices.
Precipitation	1950-94 average rainfall measured in millimeter.
Soil Erosion	Soil erosion volume measured in ton.
Temperature	1950-94 average temperature Fahrenheit.
Moisture	Percentage of acres without drought issues.
Gas Price	Five-year average dollars per gallon.
Growing Season	Measured in month.
Water: %USBR	Irrigation water sourced from USBR.
Insurance: Loss Ratio	The ratio of premium and indemnity.
Insurance: Price	Premium in dollars per thousand dollars coverage.
Insurance: Payoff Ratio	The ratio of indemnity and (premium-subsidy).
Tenant	1 if land is rented by the operator.
Full Owner	1 if land is fully owned by the operator.
Operators: %Female	Percentage of operators who are female.
Operators: Experience	Average year in current operation.
Region Dummies	See Figure 4.

Table 4: Tillage: OLS Without Controls

	Dependent variable:							
	No-till				Reduced-till			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Part	0.160	0.160	0.160	0.160	0.306***	0.306***	0.306***	0.306***
	(0.192)	(0.158)	(0.188)	(0.154)	(0.109)	(0.101)	(0.100)	(0.091)
Tenant	0.086	0.086	0.086	0.086	0.217**	0.217**	0.217**	0.217**
	(0.192)	(0.158)	(0.188)	(0.154)	(0.109)	(0.101)	(0.100)	(0.091)
Constant	−0.296*	1.236***	−0.549***	0.983***	−0.539***	−0.420***	−0.835***	−0.716***
	(0.136)	(0.214)	(0.154)	(0.217)	(0.077)	(0.137)	(0.081)	(0.128)
Time FE			✓	✓			✓	✓
Region FE		✓		✓		✓		✓
Observations	270	270	270	270	270	270	270	270
R^2	0.003	0.346	0.042	0.385	0.030	0.196	0.191	0.357
Hypothesis	Tenant=0&Part=0							
F Statistic	0.4036	0.5929	0.4206	0.6346	4.4244*	5.2495**	5.2382**	6.5482**
Hypothesis	FEs=0							
F Statistic	-	52.549***	10.658**	48.239***	-	12.953***	52.037***	37.878***

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 5: Irrigation and Insurance: OLS Estimation

	Dependent variable:							
	Irrigation				Insurance			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rainfall	−0.001	−0.005*	−0.001	−0.005**	−0.002**	−0.005**	−0.003***	−0.004*
	(0.001)	(0.003)	(0.001)	(0.003)	(0.001)	(0.002)	(0.001)	(0.002)
Temperature	0.016***	0.027***	0.016***	0.027***	0.003	0.001	0.003	0.001
	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Erosion	−0.121***	−0.083***	−0.120***	−0.083***	0.014	0.009	0.010	0.010
	(0.018)	(0.017)	(0.018)	(0.017)	(0.017)	(0.015)	(0.015)	(0.013)
Grow	−0.023**	−0.026**	−0.024**	−0.025**	−0.041***	−0.011	−0.033***	−0.014
	(0.010)	(0.012)	(0.010)	(0.012)	(0.010)	(0.011)	(0.009)	(0.010)
Moisture	−0.032	−0.051	−0.044	−0.062	0.013	−0.037	0.058	0.018
	(0.059)	(0.053)	(0.060)	(0.054)	(0.056)	(0.049)	(0.048)	(0.045)
Female	0.722***	0.289*	0.784***	0.370**	−1.430***	−0.961***	−1.843***	−1.459***
	(0.144)	(0.148)	(0.155)	(0.170)	(0.134)	(0.133)	(0.124)	(0.137)
Experience	0.005	−0.007*	0.005	−0.008**	0.018***	0.006**	0.022***	0.013***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
USBR	2.679***	2.685***	2.643***	2.674***	-	-	-	-
	(0.179)	(0.248)	(0.182)	(0.248)	-	-	-	-
Price	-	-	-	-	0.0001	0.001*	0.001**	0.001***
	-	-	-	-	(0.0004)	(0.0004)	(0.0004)	(0.0004)
Payoff	-	-	-	-	−0.013***	−0.013***	−0.004	−0.005
	-	-	-	-	(0.004)	(0.003)	(0.004)	(0.003)
Tenant	0.117***	0.016	0.118***	0.017	0.165***	0.147***	0.151***	0.140***
	(0.032)	(0.030)	(0.033)	(0.030)	(0.030)	(0.026)	(0.026)	(0.024)
Part	0.037	0.046*	0.046*	0.057**	0.060**	0.143***	0.009	0.075***
	(0.025)	(0.024)	(0.027)	(0.026)	(0.023)	(0.021)	(0.021)	(0.021)
Constant	−0.523***	−0.535***	−0.505***	−0.521***	0.610***	0.485***	0.496***	0.391***
	(0.139)	(0.163)	(0.140)	(0.164)	(0.125)	(0.145)	(0.109)	(0.131)
Time FE			✓	✓			✓	✓
Region FE		✓		✓		✓		✓
Observations	270	270	270	270	270	270	270	270
R^2	0.790	0.855	0.791	0.856	0.650	0.774	0.739	0.816
Hypothesis	FEs=0							
F Statistic	-	18.488***	1.0426	17.532***	-	13.062***	79.997***	21.129***
Hypothesis	Tenant=0&Part=0							
F Statistic	8.8952***	2.3877	9.7469***	3.0921*	13.871***	38.572***	9.5533***	18.769***

Note: *p<0.1; **p<0.05; ***p<0.01

Table 6: Tillage: IV Estimation

	Dependent variable:							
	No-till				Reduced-till			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rainfall	−0.022**	0.047**	−0.017	0.059***	−0.024***	−0.032**	−0.022***	−0.033**
	(0.011)	(0.022)	(0.013)	(0.022)	(0.006)	(0.013)	(0.007)	(0.013)
Temperature	−0.047**	−0.018	−0.044**	−0.027	−0.021*	0.001	−0.017*	0.001
	(0.021)	(0.022)	(0.020)	(0.022)	(0.011)	(0.013)	(0.010)	(0.013)
Erosion	0.167	0.167	0.186	0.181	0.270***	0.272***	0.273***	0.272***
	(0.158)	(0.131)	(0.159)	(0.129)	(0.082)	(0.077)	(0.083)	(0.077)
Moisture	1.030**	1.367***	0.782	1.190***	0.049	0.116	0.014	0.117
	(0.470)	(0.416)	(0.538)	(0.426)	(0.243)	(0.251)	(0.279)	(0.253)
Grow	0.533***	0.500***	0.542***	0.613***	0.162***	0.265***	0.162***	0.263***
	(0.082)	(0.094)	(0.087)	(0.101)	(0.043)	(0.058)	(0.045)	(0.060)
Fuel	−1.685***	−1.647***	−0.701	2.945	−1.583***	−1.451	−1.245	−1.431
	(0.261)	(0.245)	(1.485)	(1.844)	(0.135)	(1.099)	(0.770)	(1.094)
Gender	−2.795	−2.205	0.529	3.345	−4.505**	−4.223***	−3.229	−4.348*
	(4.054)	(2.378)	(6.081)	(4.045)	(2.097)	(1.398)	(3.153)	(2.401)
Experience	0.002	−0.002	−0.035	−0.061	0.041	0.006	0.026	0.007
	(0.052)	(0.034)	(0.072)	(0.047)	(0.027)	(0.020)	(0.038)	(0.028)
Part	−0.681**	−1.047***	−0.585***	−0.926***	−0.200	0.018	−0.221*	0.027
	(0.271)	(0.344)	(0.219)	(0.279)	(0.140)	(0.203)	(0.114)	(0.166)
Tenant	−0.543	−0.786**	−0.714	−1.068**	0.097	0.052	−0.012	0.066
	(0.479)	(0.380)	(0.508)	(0.434)	(0.248)	(0.223)	(0.263)	(0.257)
Fitted_irri	−1.481***	−3.492***	−1.572***	−3.646***	−0.612**	−2.461***	−0.641**	−2.465***
	(0.546)	(0.744)	(0.562)	(0.738)	(0.283)	(0.437)	(0.291)	(0.438)
Fitted_ins	2.290	3.963*	3.624	6.286**	−0.178	−0.476	0.561	−0.573
	(2.630)	(2.026)	(3.107)	(2.628)	(1.361)	(1.194)	(1.611)	(1.560)
Constant	2.647	−1.054	−1.201	−18.145***	5.119***	3.305	3.612	3.272
	(2.015)	(1.871)	(5.122)	(6.942)	(1.042)	(4.151)	(2.656)	(4.120)
Time FE			✓	✓			✓	✓
Region FE		✓		✓		✓		✓
Observations	270	270	270	270	270	270	270	270
R^2	0.372	0.593	0.376	0.605	0.494	0.580	0.495	0.580
Note:						*p<0.1; **p<0.05; ***p<0.01		

Table 7: 3SLS Estimation

	Dependent variable:							
	No-till		Reduced-till		Irrigation		Insurance	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rainfall	−0.01	0.06*	−0.02**	−0.03*	−0.00	−0.00	−0.01	−0.00
	(0.02)	(0.02)	(0.01)	(0.01)	(0.00)	(0.00)	(0.02)	(0.00)
Temperature	−0.06**	−0.03	−0.02	0.01	0.01	0.01***	−0.08	−0.00
	(0.02)	(0.03)	(0.01)	(0.01)	(0.00)	(0.00)	(0.12)	(0.00)
Erosion	0.22	0.19	0.28***	0.29***	−0.09***	0.01	−0.28	0.01
	(0.17)	(0.14)	(0.08)	(0.08)	(0.02)	(0.02)	(0.47)	(0.01)
Moisture	0.86	1.28**	0.02	0.13	0.10	0.08	2.42	0.08
	(0.53)	(0.46)	(0.24)	(0.25)	(0.12)	(0.07)	(3.69)	(0.06)
Grow	0.62***	0.61***	0.17*	0.16*	0.06	0.04*	0.84	0.00
	(0.15)	(0.14)	(0.07)	(0.08)	(0.04)	(0.02)	(1.33)	(0.01)
Female	−0.18	2.22	−3.32	−6.53*	0.73*	−0.83	−4.94	−1.64***
	(5.70)	(5.13)	(2.65)	(2.83)	(0.31)	(0.55)	(5.74)	(0.17)
Experience	−0.03	−0.05	0.03	0.03	−0.00	0.00	0.01	0.01***
	(0.07)	(0.06)	(0.03)	(0.03)	(0.00)	(0.01)	(0.05)	(0.00)
Fuel	−0.84	4.27	−1.43***	−1.92	-	-	-	-
	(0.84)	(2.22)	(0.39)	(1.22)	-	-	-	-
USBR	-	-	-	-	2.27***	1.30***	-	-
	-	-	-	-	(0.25)	(0.26)	-	-
Payoff	-	-	-	-	-	-	−0.04	−0.01*
	-	-	-	-	-	-	(0.06)	(0.00)
Price	-	-	-	-	-	-	0.01	0.00**
	-	-	-	-	-	-	(0.02)	(0.00)
Insurance	3.50	5.52	0.53	−1.93	0.37*	−0.11	-	-
	(3.33)	(3.31)	(1.54)	(1.83)	(0.16)	(0.38)	-	-
Irrigation	−1.16	−3.57***	−0.55	−2.28***	-	-	−2.30	−0.07
	(0.65)	(0.75)	(0.30)	(0.42)	-	-	(3.30)	(0.11)
No-till	-	-	-	-	−0.15	−0.07	−2.56	−0.06
	-	-	-	-	(0.10)	(0.04)	(3.80)	(0.04)
Reduced-till	-	-	-	-	0.08	−0.12*	2.90	0.04
	-	-	-	-	(0.12)	(0.05)	(4.33)	(0.05)
Part	−0.63*	−0.88**	−0.23	0.09	−0.03	−0.01	−0.72	0.05
	(0.25)	(0.32)	(0.12)	(0.17)	(0.04)	(0.05)	(1.24)	(0.03)
Tenant	−0.74	−0.95	−0.01	0.26	0.01	0.01	−0.51	0.13***
	(0.60)	(0.53)	(0.28)	(0.29)	(0.05)	(0.06)	(1.09)	(0.03)
Constant	−0.82	−22.58*	4.26	5.75	−0.88***	−0.79**	−3.43	0.20
	(4.67)	(8.77)	(2.17)	(4.83)	(0.20)	(0.26)	(6.24)	(0.19)
FEs		✓		✓		✓		✓
Obs	270	270	270	270	270	270	270	270

Note: *p<0.05; **p<0.01; ***p<0.001

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