An Analysis of the Impact of Drought on Agriculture, Local Economies, Public Health, and Crime Across the Western United States

Dale Manning, Jesse Burkhardt,
Chris Goemans, Alex Maas

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Dale Manning
Associate Professor
Department of Agricultural and Resource Economics
Colorado State University

Jesse Burkhardt
Assistant Professor
Department of Agricultural and Resource Economics
Colorado State University

Chris Goemans
Associate Professor
Department of Agricultural and Resource Economics
Colorado State University

Alex Maas
Assistant Professor
Department of Agricultural Economics and Rural Sociology
University of Idaho

Executive Summary

Overview

We estimate the average impact of drought on a wide-variety of economic and social indicators over a forty-year period across the western U.S. Estimated impacts are then used to simulate the specific effects of particular droughts. Importantly, our approach distinguishes between the effect of prolonged drought conditions (as measured by PDSI) and the impact of contemporaneous variation in temperature and precipitation. Thus, simulated impacts reflect the combined effect associated with both prolonged drought conditions and short-term weather conditions within a given year.

Our analysis utilizes county level data from the last 40 years to generate estimates of the average impact that monthly drought conditions over the course of a year have on each of the outcome indicators considered. In addition to generating average estimates, we also explore how the timing of drought conditions within a year, as well as whether a county is groundwater dependent, impacts the average effect.

Estimates generated from the statistical analysis are then used to simulate the effects of specific drought years on specific counties. While this report examines the impact of periods of extreme drought and extreme wet, the following summary of results focuses on extreme drought which was the original motivation for this study. References to positive or negative effects in the following summary are only made if the estimated impact was statistically different from zero.

Summary of Results

Agricultural Productivity Impacts

- Prolonged drought has a negative and statistically significant impact on corn, hay, sorghum, and wheat production.[1] Each additional month of extreme drought conditions (PDSI<-3) is associated with a decrease in total corn and wheat production of 3.2 and 3.6 percent, respectively.
- All else constant, higher temperatures and precipitation have a positive and statistically significant impact on total production; however, these effects are diminishing with higher temperatures and become negative for conditions well above the mean.
- Heterogeneity exists in terms of the average effect of an additional month of drought on crop production. Not surprisingly drought conditions that occur during the growing season have a much larger negative impact on total production than those that occur during the non-growing season.
- For corn and wheat, the reduction in total production is largely driven by a decrease in harvested acres, whereas for hay the reduction in total production is primarily due to a decrease in yields per acre harvested.
- Although less clear, the impacts on agricultural production appear to be lower in counties with higher median household incomes.
- In the Appendix, we include estimates of the impact of watershed-level drought (drought measures at the HUC level). We find that the impact of a watershed-level drought is qualitatively similar to the impact of a county specific drought, which is unsurprising given that the two are correlated. However, the watershed-level drought impacts are muted in comparison to the county specific drought.

Impacts to Wages, Employment and Number of Establishments

- The effect of extreme drought conditions on total wages paid to employees across all sectors is not statistically different from zero, as total wages decrease in some industries and increase in others.
    - For agriculture supply and agricultural, fishing, and hunting, each additional month of extreme drought within a given year is associated with a reduction in total wages paid to employees in that sector of approximately 1.2 percent and 0.5 percent, respectively.
    - Extreme drought has a positive association with wages paid to employees in the public utilities.

[1] We chose these crops because they are the most abundant in the USDA QuickStats data. Data on other crops are sparsely available.

    - An additional month of extreme drought reduces wages in the broader recreation and entertainment industry by 0.59 percent.
- Similar to wages, the effect of extreme drought on total employment is not significantly different from zero, however, the result is mixed across different sectors.
    - Each additional month of extreme drought within a given year is associated with a reduction in total employment in the agricultural supply, livestock production, and agricultural, fishing, and hunting sectors of approximately 1.2 percent, 0.6 percent, and 0.5 percent respectively.
    - Each additional month of extreme drought also has a negative impact on the recreation and entertainment sectors.
- Severe drought leads to a modest, but statistically significant decrease in the overall number of businesses. The negative effect is largely due to decreases in the recreation and entertainment, service, agricultural supply, and trade sectors.
    - The percent decrease in the number of agricultural establishments is largest in the recreation and entertainment (0.5%) and agricultural supplier sectors (0.7%).

Health Outcomes

- Drought is generally uncorrelated with annual, county-level health outcomes, with the exception that an additional month of extreme drought is associated with a 0.5 percent reduction in heart disease mortality.

Criminal Activity

- Drought is generally uncorrelated with annual, county-level criminal activity, with the exception that an additional month of moderate drought is associated with small reductions in simple assaults and property crimes.

Insurance Outcomes

- An additional month of extreme drought is associated with a 10 percent and 7 percent increase in indemnity amounts and insurance policy counts, respectively. An additional month of moderate drought is associated with a 6.5 percent and 4.7 percent increase in indemnity amounts and insurance policy counts, respectively.
- Drought is uncorrelated with liability amounts.

Total Taxes and Total Revenue

- An additional month of extreme drought is associated with a 0.4 percent increase in total revenue, while an additional month of moderate drought is associated with a 0.3 percent increase in total taxes.

Introduction

Severe, extreme, or exceptional drought conditions have become increasingly common throughout the western United States over the past 20 years. Abnormally dry conditions can lead to a wide range of negative economic impacts across a wide range of sectors that either directly or indirectly depend on weather-dependent ecosystem services. Examples include agricultural production, where yields are negatively impacted by inadequate water supplies, and tourism, where lower stream flows and snowpack can change the attractiveness of both winter and summer tourism activities. In both of these instances, the impacts are likely to extend beyond just those sectors directly impacted and beyond traditional economic indicators. The goal of this study is twofold. First, utilizing approximately 40 years of county level data from across the western United States[2], we attempt to empirically identify the impact of drought on society. This includes characterizing how drought impacts agricultural productivity, employment, wages paid, business openings/closings, criminal activity, and health outcomes. Our second objective is to develop a low-cost, spatially and temporally generalizable means of simulating the impact of specific droughts on society. This information not only helps in terms of responding to the current drought, but also aims to inform planners and policymakers of the potential changes that will result as drought becomes more frequent.

Water provides a critical input to many resource-based activities that make up a large part of the economy throughout the western US. For example, water shortages in agriculture can lead to reductions in yield and revenue in the immediate term, while lower stream flows can impact demand for boating and fishing activities and extreme heat can deter potential tourists from visiting a region. As drought becomes more frequent, we will likely see changes throughout the entire economy. For example, lower snowpack attracts fewer skiers and winter sports enthusiasts, leading to decreased demand for hotels, restaurants and other services utilized by tourists. As tourism-oriented sectors are directly affected, input suppliers may also be impacted, creating economy-wide ripples that lead to lower incomes and government revenue for the provision of public services.

Previous studies examining drought in Colorado have largely focused on the direct impacts to agriculture and the indirect effects associated with sectors related to agriculture. They have also typically focused on the impacts to a single region stemming from a particular drought. Examples include Goemans et al. (2013), Pritchett et al. (2013), and Bauman et al. (2014). These studies have attempted to estimate the magnitude of the impacts on agriculture resulting from drier than normal conditions while also detailing the economy-wide implications of lost agricultural activity. Direct economic impacts to other sectors (and their corresponding indirect effects) have largely been ignored given the focus on agriculture. The results presented herein represent the cumulative, general

[2] Specifically, our analysis includes data from the following states: Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, New Mexico, Oklahoma, Oregon, Texas, Utah, Washington, and Wyoming.

equilibrium impacts associated with the combined direct and indirect impacts of drought to all economic sectors.

Furthermore, despite anecdotal evidence suggesting that drought's impacts extend beyond traditional economic indicators[3], little work has examined how drought impacts health and crime outcomes. This study aims to assess the impacts of the 2018 drought on agriculture, providing a point of comparison to previous droughts, but also to broaden the scope of indicators examined. Unlike previous efforts, this study uses an empirical approach (multivariate regression) that assesses impacts using actual experiences with drought over time. We utilize this approach as it requires few assumptions relative to the structural models traditionally used in conducting drought impact analysis and is easily transferable across regions/droughts.

Methodological Approach and Data

Estimating Marginal Impacts

In the simplest of terms, drought corresponds to the absence of water.[4] Available water supply and demand are the cumulative result of historic weather conditions combined with contemporaneous weather conditions.[5] In this sense drought conditions can be characterized in terms of a stock and flow. Weather events leading up to any given year result in a "stock" of available water to which contemporaneous weather events in that year build off of (i.e., the "flow"). To understand the importance of making this distinction consider the impact of a period of excessive rainfall (flow) that occurs following a prolonged period with low soil moisture (stock) as compared to one that occurs when soils are extremely wet.

With this distinction in mind, we utilize the following base statistical model to capture the short-term impact of prolonged drought (i.e. the stock of available water) and contemporaneous weather (i.e. the flow) on a range of outcomes (e.g., corn acres harvested).

$$l\,n\left(Y_{it}^{j}\right) = \theta_W Weather_{it} + \sum_{k=1}^{4} \beta_k\, Category_{it}^{k} + \alpha_i + \gamma_t + \epsilon_{it}^{j}. \quad (1)$$

[3] https://www.denverpost.com/2018/10/03/colorado-farmers-mental-health/

[4] Multiple definitions of drought exist, some specific to the impacted area (e.g., agricultural drought, hydrologic drought, etc.). For a more comprehensive discussion of the different types and causes of drought see: https://drought.unl.edu/Education/DroughtIn-depth/TypesofDrought.aspx

[5] Contemporaneous demand for water depends on contemporaneous weather conditions in so far as households and farms require water for irrigation. For example, if there is less precipitation in a given year, the demand for municipal and irrigation water will increase.

Y_{it}^{j} is outcome j in county i in year t. A complete list of outcomes is provided below in Table 1. $Weather_{it}$ is a vector of contemporaneous weather variables including annual precipitation, annual precipitation squared, annual average temperature, and annual average temperature squared. $Category_{it}^{k}$ is intended to reflect the stock effect and corresponds to the number of months in a given year that fall into drought category k.

Given this specification, θ_W provides an estimate of the impact of contemporaneous weather conditions (the flow effect) on each outcome whereas β_k provides an estimate of the impact of an additional month of $Category^{k}$ on a particular outcome.

One obvious concern is that agricultural and economic outcomes (Y_{it}^{j}) are likely correlated with other non-drought variables, and if those variables are not accounted for, our drought impact estimates will be biased. To address such concerns, we include additional variables as controls for potentially confounding factors between outcomes Y_{it}^{j} and drought. Specifically, we include county fixed effects (α_i) which control for any time-invariant county specific unobserved variables such as average soil type, elevation, and time-invariant management practices. We also include year fixed effects (γ_t) to account for any time-varying unobserved variables such as macroeconomic trends, commodity price trends, and geographically broad production trends. All standard errors are clustered at the county level.

Simulating Drought Impacts

The statistical methodology outlined in Equation 1 produces the average marginal effect of changes in weather and the PDSI over a 40-year period across the entire West. In this section, we use our model to produce disaggregated estimates for particular counties in particular years. To do so, we combine county specific drought, temperature, and precipitation data with the output from our model in Equation 1. The procedure proceeds in two steps. First, we estimate the model in Equation 1 to produce estimates of the model parameters including $\hat{\theta}_W$ and $\hat{\beta}_k$.[6] Second, we plug the county-year specific data into the model output to generate county-year specific drought impact estimates. For instance, for Weld County, Colorado in 2012, we could write:

$$\begin{aligned}\text{Impact}^{\text{Y}}_{\text{Weld,2012}} &= \hat{\theta}_W\left(Weather_{Weld,2012} - \underline{Weather_{Weld}}\right) \\ &+ \sum_{k=1}^{4} \hat{\beta}_k \left(Category^{k}_{Weld,2012} - \underline{Category^{k}_{Weld}}\right) \quad (2)\end{aligned}$$

[6] Estimated parameters, for example β, are denoted with hats as in "$\hat{\beta}$".

where $\text{Impact}^{Y}_{\text{Weld},2012}$ corresponds to the proportional deviation from normal for outcome Y in Weld county, CO associated with the temperature, precipitation and $PDSI$ conditions for 2012. $Weather_{Weld,2012}$ includes the data on precipitation, precipitation squared, temperature, and temperature squared for Weld County in 2012. $\underline{Weather_{Weld}}$ represents the mean values for each variable for Weld county over the period of analysis. Likewise, $Category^{k}_{Weld,2012}$ includes the PDSI data for Weld County in 2012 and $\underline{Category^{k}_{Weld}}$ corresponds to the mean number of months within a year in each category for Weld county. The impact from our simulation, when multiplied by 100, is the estimated percentage change in outcome Y relative to what could have been expected under normal conditions.

Data

The variable $Category$ is created using the Palmer Drought Severity Index (PDSI) sourced from the Climate Engine, which uses data from gridMET (Abatzoglou et. al, in press).[7] PDSI is designed to capture droughts occurring on time scales longer than 12 months, or to capture the presence of prolonged drought (Dai, 2019). PDSI is a water budget based approach that is calculated using a variety of water supply and demand variables to develop a cumulative measure of water deficit excess.

We bin PDSI values into one of 5 categories. Specifically, to calculate the number of months in each year corresponding to category k we sum the number of months within a given county (i) and year (t) that fall within each of the following categories: less than -3, -1 to -3, -1 to 1, 1 to 3 and greater than 3. Moving forward we refer to each of these categories as extreme drought, moderate drought, normal conditions, moderate wet, and extreme wet respectively. For example, $Category^{1}_{it}$ is equal to the number of months that county (i) experienced in year (t) that were classified as extreme drought. When estimating Equation 1, the "normal conditions" bin is omitted so that the coefficients on the drought conditions and wet conditions bins are interpreted as relative to normal conditions. Thus, the coefficient estimates, when multiplied by 100, represent the average percent change in the outcome variable associated with 1 additional month in each particular category. One advantage to binning PDSI in this way (as opposed to, for example, only counting the number of months for which PDSI<-3) is that we are able to identify the effect of abnormal conditions, whether dry or wet, on each of the outcome indicators.

We also estimate a series of models in which we separate the bins into growing season and non-growing season aggregates. This is done to estimate the impact of drought at different times of the

[7] We note that this is the same data that can be downloaded from Google Earth Engine. NOAA also has PDSI data, however, NOAA's data is aggregated to the climate division level, which is larger than the county. In email exchanges with NOAA, we also discovered that the data presented in the maps on their website is not always accurate.

year. The growing season is defined as April-September while the non-growing season is defined as October-March.

Table 1A: Outcome Indicators and Data Sources

Category	Variable Name	Data Source	Geographic Scale	Temporal Scale	Temporal Coverage
Employment, Wages, and Number of Establishments					
	Employment	QCEW	County	Monthly	1980-2016
	Total Wages Paid	QCEW	County	Monthly	1980-2016
	Number of Establishments	QCEW	County	Monthly	1980-2016
Agricultural					
	Total Production	NASS	County	Annual	1980-2016
	Acres Harvested	NASS	County	Annual	1980-2016
	Yield per Acre	NASS	County	Annual	1980-2016
Health					
	Opioid	CDC	County	Monthly	1980-2016
	Alcohol	CDC	County	Monthly	1980-2016
	Heart Disease	CDC	County	Monthly	1980-2016

Criminal Activity					
	Aggravated Assault	FBI-UCRS	County	Monthly	1980-2016
	Simple Assault	FBI-UCRS	County	Monthly	1980-2016
	Property Crime	FBI-UCRS	County	Monthly	1980-2016
	Violent Crime	FBI-UCRS	County	Monthly	1980-2016
Insurance					
	Liability Amount	RMA	County		1989-2010
	Indemnity Amount	RMA	County		1989-2010
	Count of Indemnity Policies	RMA	County		1989-2010
Total Revenue and Total Taxes					
	Total Revenue	Government Finance Database[8]	County		1980-2015
	Total Taxes	Government Finance Database	County		1980-2015

[8] Pierson K., Hand M., and Thompson F. (2015). The Government Finance Database: A Common Resource for Quantitative Research in Public Financial Analysis. *PLoS ONE* doi: 10.1371/journal.pone.0130119

Table 1B: Right Hand Side Variables and Data Sources

Variable Name	Data Source	Geographic Scale	Temporal Scale	Temporal Coverage
PDSI	Climate Engine (GridMET)	County	Monthly	1980-2020
Temperature	PRISM	County	Daily	1980-2020
Precipitation	PRISM	County	Daily	1980-2020

Table 2: QCEW Sector Mapping

Variable Name		NAICS Sector Name	NAICS Code
All		**All Industries**	
AgFishHunt		Agriculture, Forestry, fishing, and hunting	1
	Crop Production	Crop Production	111
	Livestock	Animal Production and Aquaculture	112
	Ag Supply	Support Activities for Agriculture and Forestry	
Recreation and Entertainment		Arts, Entertainment, and Recreation	71
	Fish	Fishing, Hunting and Trapping	114
	Travel Accommodation	Traveler Accommodation, Drinking Places, Restaurants and Other Eating Places, Beer, Wine, and Liquor Stores, Leisure and Hospitality	7211, 7224, 7225, 4453, 1026
Education and Health		Educational Services, Health Care and Social Assistance	6
Manufacturing		Manufacturing	3
Other		Public Administration	9

Service	Information, Finance and Insurance, Real Estate and Rental Leasing, Professional, Scientific and Technical Services, Management of Companies and Enterprises, Admin and Support, Other Services	50, 81
Trade	Wholesale Trade, Retail Trade, Transportation and Warehousing	4
Utilities and Construction	Utilities, Mining, Quarrying, Oil and Gas Extraction, and Construction	2

Note: Sectors contain all sub-sectors that begin with the NAICS code listed above. For example, EducHealth includes NAICS sectors 61 and 62. Complete definition for all sectors can be found online at: https://www.census.gov/cgi-bin/sssd/naics/naicsrch?chart=2017

Results

We begin by presenting results of estimating Equation 1 for each outcome variable in our data. First, we present agricultural impacts. Agricultural impacts are presented graphically whereas the full regression results tables are presented for the other outcomes[9]. Second, we present other non-agricultural economic sector impacts including the impact of drought on wages and number of establishments in each sector. We conclude by presenting the impacts of drought on public health, crime, insurance measures, and government revenue and taxes.

Agricultural Impacts

Figure 1 illustrates the impact of an additional month in each PDSI category (the bins defined above) on total production for each of the four crops analyzed as part of this study. We chose to analyze corn, hay, wheat, and sorghum because there were too few observations of other crops such as dry beans and potatoes to provide statistically meaningful results. For each PDSI category, the dot corresponds to the estimated proportional impact of an additional month in that category, relative to baseline conditions ($-1 \leq PDSI \leq 1$); the lines extending out from the dot cover the 95 percent confidence interval. When multiplied by 100 the point estimate provides the estimated percentage change in each outcome indicator. Consistent with expectations, all else equal, a month of extreme or moderate drought has a negative and statistically significant impact on total production. Each month of extreme drought (PDSI<-3) reduces total corn production by approximately 3.2 percent, hay production by approximately 2.2 percent, wheat production by approximately 3.8 percent, and sorghum production by approximately 2.7 percent. Similarly, each month of moderate drought (-1>PDSI>-3) reduces corn, hay, wheat, and sorghum production by 0.9 percent, 0.8 percent, 1.9 percent, and 1.7 percent respectively. In contrast, we find that abnormally wet periods slightly decrease corn, hay and wheat production, but increase sorghum production.

To better understand the effect of pro-longed drought on total production we separately examine how yields and acres harvested are impacted by different PDSI conditions.[10] These results are presented in Figures 2 and 3. Figure 2 presents the proportional impacts of an additional month in each PDSI category on per acre yields for corn, hay, wheat, and sorghum. We find that an additional month of extreme drought (PDSI<-3) reduces corn, hay, wheat, and sorghum yields by approximately 1.5, 1.9, 1.6, and 2.5 percent respectively. An additional month of moderate drought (-3<PDSI<-1) decreases hay, wheat, and sorghum yield by approximately 0.5, 0.8, and 0.7 percent respectively. Finally, an additional month of extreme wet conditions (PDSI>3) decreases corn, hay, wheat, and sorghum yields by 1, 0.3, 0.8, and 0.9 percent respectively.

[9] The full set of results for agriculture are presented in the Appendix.

[10] Total production is the production in lbs, bushels, or other physical measurement per county per year. Total acres harvested is measured in acres per county per year. Yield is the ratio of production per acres harvested.

Figure 3 presents the proportional impacts of an additional month in each PDSI category on harvest for corn, hay, wheat, and sorghum. We find that an additional month of extreme drought (PDSI<-3) reduces corn, hay, and wheat harvests by approximately 1.6, 0.4, and 2 percent respectively. An additional month of moderate drought (-3<PDSI<-1) decreases corn, hay, and wheat harvests by approximately 0.7, 0.4, and 1 percent respectively. An additional month of moderately wet conditions (1<PDSI<3) does not statistically significantly impact hay, wheat, and sorghum harvests. Sorghum harvests are positively correlated wet conditions.

The results suggest that, at least for corn and wheat, the reduction in total production is largely driven by a decrease in harvested acres as opposed to a reduction in yield. For these two crops, the results suggest (consistent with Manning et al. 2016) that producers respond by adjusting on the extensive margin (i.e., concentrating limited resources on limited number of acres), as opposed to the intensive margin (i.e., maintaining the same number of acres, but reducing the quantity of water resources dedicated to each acre). This has important implications for economy-wide impacts as a reduction in acres harvested is likely to result in larger impacts to backward-linked industries than those associated with a reduction in per acre yields. The full set of results for agriculture are presented in Tables A1-A3 in the Appendix.

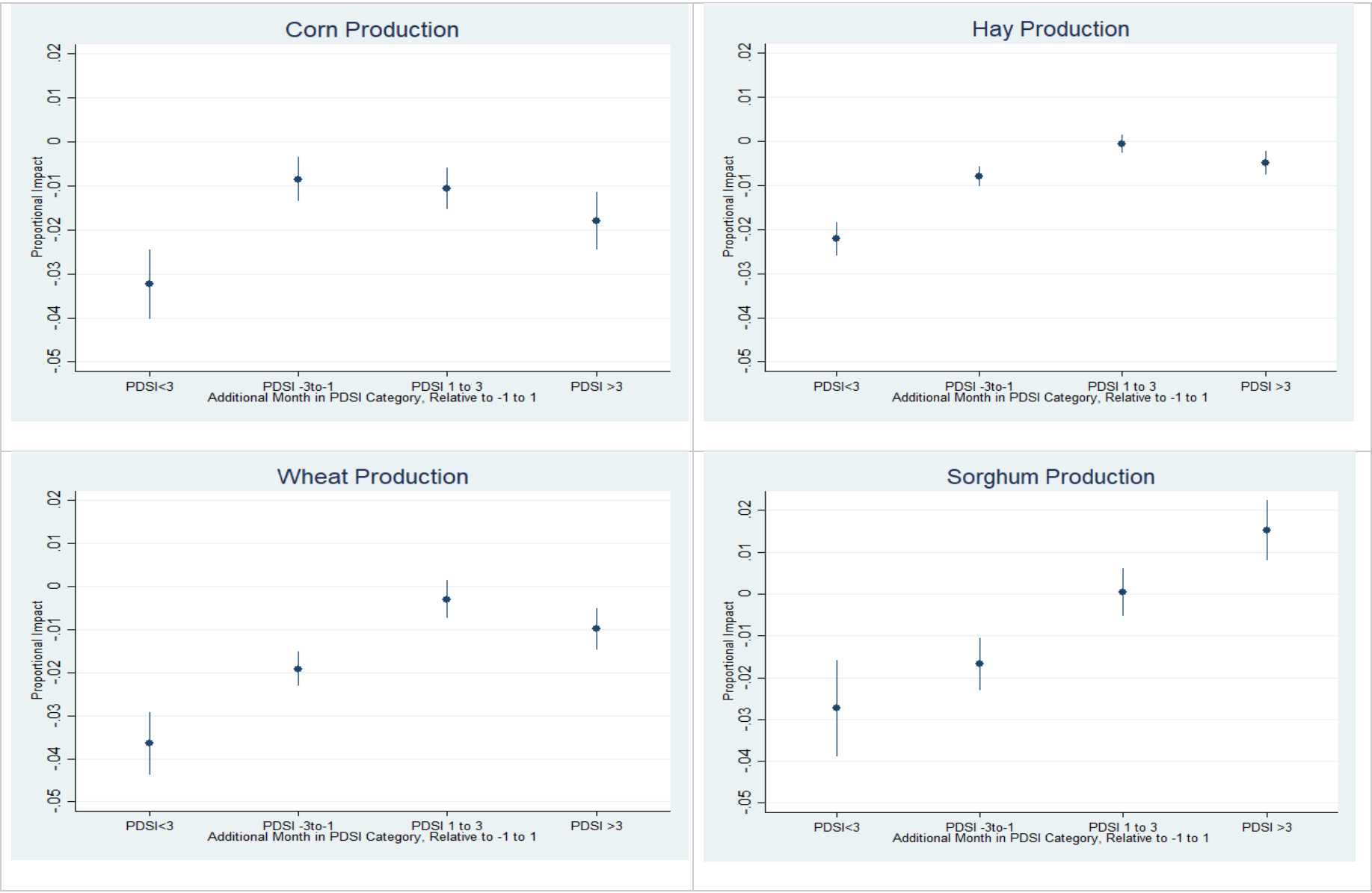


Figure 1: Proportional Drought Impacts on Corn, Hay, Wheat, and Sorghum Total Production

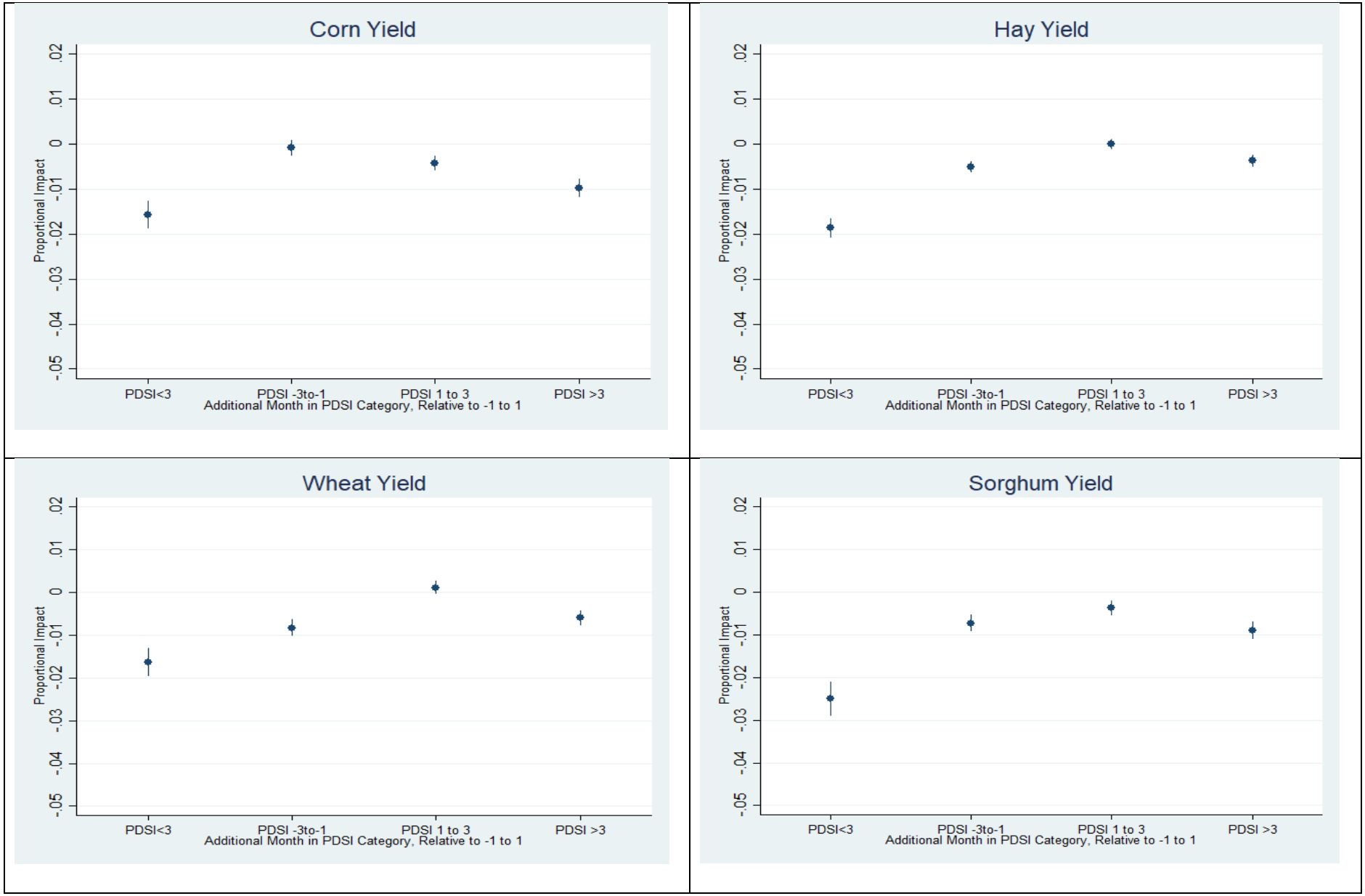


Figure 2: Proportional Drought Impacts on Corn, Hay, Wheat, and Sorghum per Acre Yields

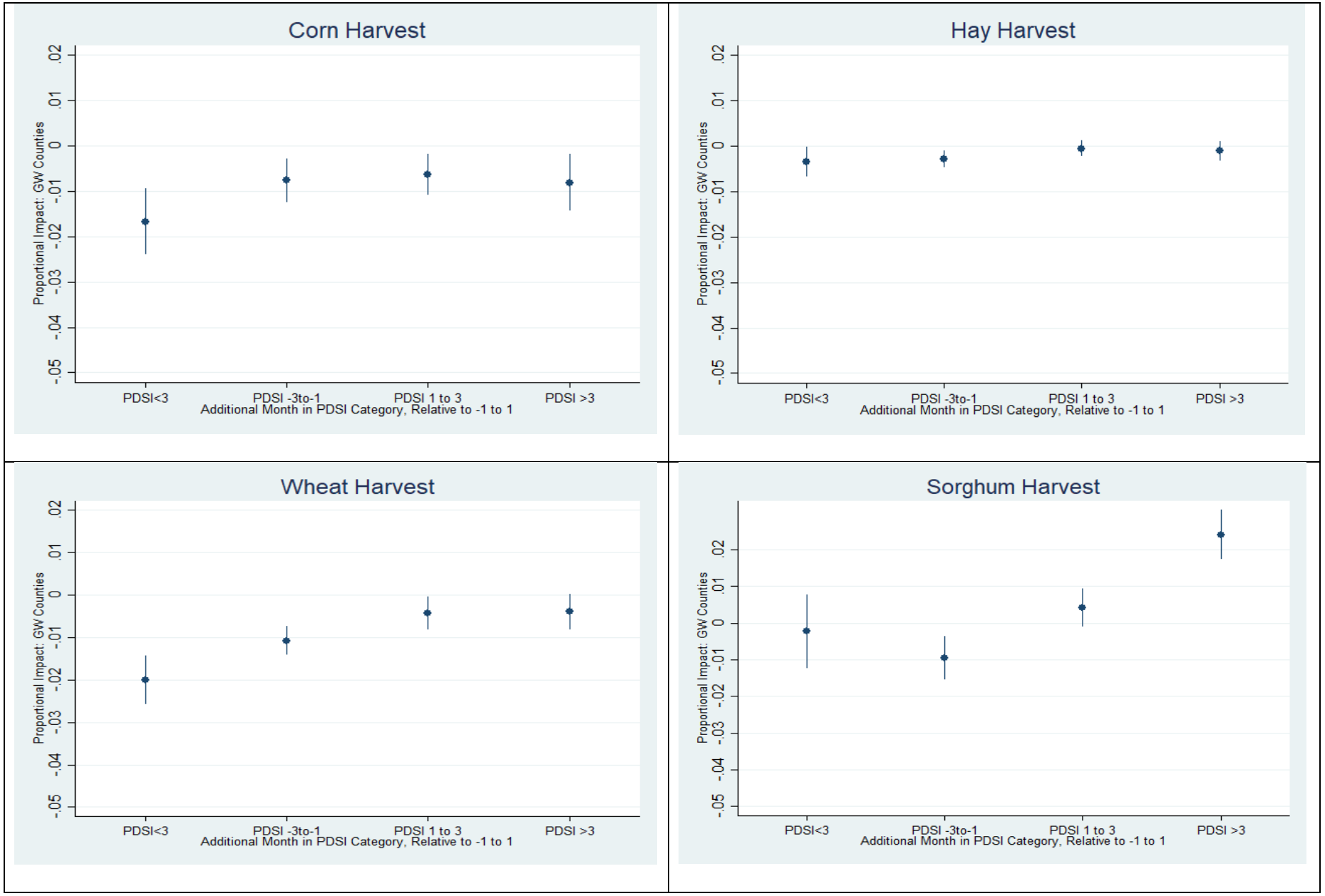


Figure 3: Proportional Drought Impacts on Corn, Hay, Wheat, and Sorghum Harvested Acres

Heterogeneity in Drought Impacts on Total Production

In addition to estimating average marginal impacts, we also explore whether drought impacts depend on the within year timing of drought conditions (e.g., growing season versus non-growing season), the extent to which an area has historically been dependent on groundwater for production, and the geographic scope of the drought. Figure 4 presents the growing season versus non-growing season drought impacts on total production for corn and hay. We find that an additional month of extreme drought (-3<PDSI) during the growing season decreases corn and hay production by 4.8 and 4.2 percent respectively, substantially more than the average annual drought impacts presented above. Additionally, an additional month of moderate drought (-3<PDSI<-1) during the growing season decreases hay production by approximately 0.8 percent but does not statistically impact corn production. In contrast, moderately wet and extreme wet months during the growing season have opposing effects on corn and hay production: corn production decreases under wet growing season conditions while hay production is largely unaffected.

Drought conditions in the non-growing season also impacts corn and hay production in interesting ways. Drought in the non-growing season is negatively correlated with corn production, but the results are statistically insignificant. Whereas moderate drought in the non-growing season is statistically negatively correlated with hay production. Moderately wet and extreme wet months during the non-growing season substantially increase corn production but decrease hay production.

Complete growing season and non-growing season results for all crops, including the impact on total production, per acre yields, and harvested acres are presented in Appendix A7-A9. Figure 4 highlights the importance of the timing of drought conditions within a year and how this importance varies depending on the crop in question. Corn and hay production are clearly more sensitive to drought during the growing season. Interestingly, wet conditions during the non-growing season substantially improve corn production but do not appear to improve hay production. These discrepancies highlight the differences in how each crop utilizes water over the course of the year.

Figure 5 evaluates whether the impacts of drought on corn and hay production depend on whether a county is dependent on groundwater. The results show that the impact of drought on corn production is largely unaffected by the dependence on groundwater. In contrast, the impact of drought on hay production is largely remedied by groundwater. Again, full regression results for these crops and wheat and sorghum are presented in Tables A4-A6 Appendix.

We also examine the relationship between drought impacts and median household income within a county. To do so, we interact the PDSI bins with the county level 5-year average median household income from the from American Consumer Survey (US Census Bureau, 2010). The results are presented in Table 3 below. The impact of drought on each crop is qualitatively similar to the non-interacted models presented in the figures above, however the standard errors on the point estimates tend to increase. The important takeaway from this table is that when statistically significant, the

interaction terms are positive indicating that higher incomes tend to reduce the impact of drought (the positive interaction term is added to the negative drought impact, reducing the overall magnitude of the impact).

Finally, we explore the impact of drought at larger geographic extents. To do so, we calculate the PDSI bins at the hydrologic unit code (HUC) subregion level. The HUCs are analogous to watersheds. The results are presented in Tables A10 and A11 in the Appendix. Table A10 includes both the county level PDSI bins and the HUC level PDSI bins, whereas Table A11 includes only the HUC level PDSI bins. Watershed level drought and county specific drought are highly correlated and the results reflect this. We find that an additional month of a HUC level drought has qualitatively the same effect as a county level drought, but the magnitude of the effect is smaller. This is likely due to the fact that the county drought measures are localized to the county, whereas the HUC level drought measures include drought conditions in other parts of the country, which introduces measurement error into the drought variables.

Table 3: Agricultural Results with PDSI Interacted with Median Household Income Per County

VARIABLES	**(1)** **Corn**	**(2)** **Hay**	**(3)** **Wheat**	**(4)** **Sorghum**
PDSI<-3	-0.0191	-0.0220**	-0.0743***	-0.0669**
	(0.0213)	(0.0105)	(0.0211)	(0.0313)
PDSI -3 to-1	-0.0396**	0.00216	-0.0270**	-0.0466***
	(0.0154)	(0.00658)	(0.0109)	(0.0150)
PDSI 1 to 3	-0.0147	0.00486	-0.0320**	-0.00338
	(0.0141)	(0.00562)	(0.0128)	(0.0136)
PDSI >3	-0.0630***	-0.0164***	-0.0170	0.0228
	(0.0172)	(0.00628)	(0.0134)	(0.0166)
PDSI<-3*Income	-0.000302	-3.48e-06	0.000875*	0.000906
	(0.000465)	(0.000237)	(0.000479)	(0.000713)

PDSI -3 to-1*Income	0.000714**	-0.000230	0.000188	0.000698**
	(0.000351)	(0.000145)	(0.000246)	(0.000341)
PDSI 1 to 3*Income	9.55e-05	-0.000124	0.000675**	9.26e-05
	(0.000321)	(0.000124)	(0.000287)	(0.000308)
PDSI >3*Income	0.00104***	0.000260*	0.000169	-0.000179
	(0.000381)	(0.000134)	(0.000305)	(0.000385)
Annual average temperature	0.268***	0.0773***	0.234***	0.270***
	(0.0447)	(0.0210)	(0.0303)	(0.0607)
Annual average temperature squared	-0.00894***	-0.00292***	-0.00643***	-0.00524***
	(0.00123)	(0.000599)	(0.000856)	(0.00146)
Precipitation	0.000667***	0.000549***	0.000177*	0.00120***
	(0.000129)	(4.64e-05)	(0.000103)	(0.000183)
Precipitation squared	-3.57e-07***	-1.30e-07***	-2.30e-07***	-5.76e-07***
	(6.80e-08)	(1.62e-08)	(4.74e-08)	(9.44e-08)
Constant	11.11***	9.892***	11.41***	9.053***
	(0.432)	(0.193)	(0.296)	(0.711)
Observations	14,488	16,671	18,697	12,908
R-squared	0.334	0.125	0.177	0.224
Number of fips	618	773	808	544

Robust standard errors in parentheses. Income measured in $1,000s. We are using 2010 5-year median household income estimates.

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

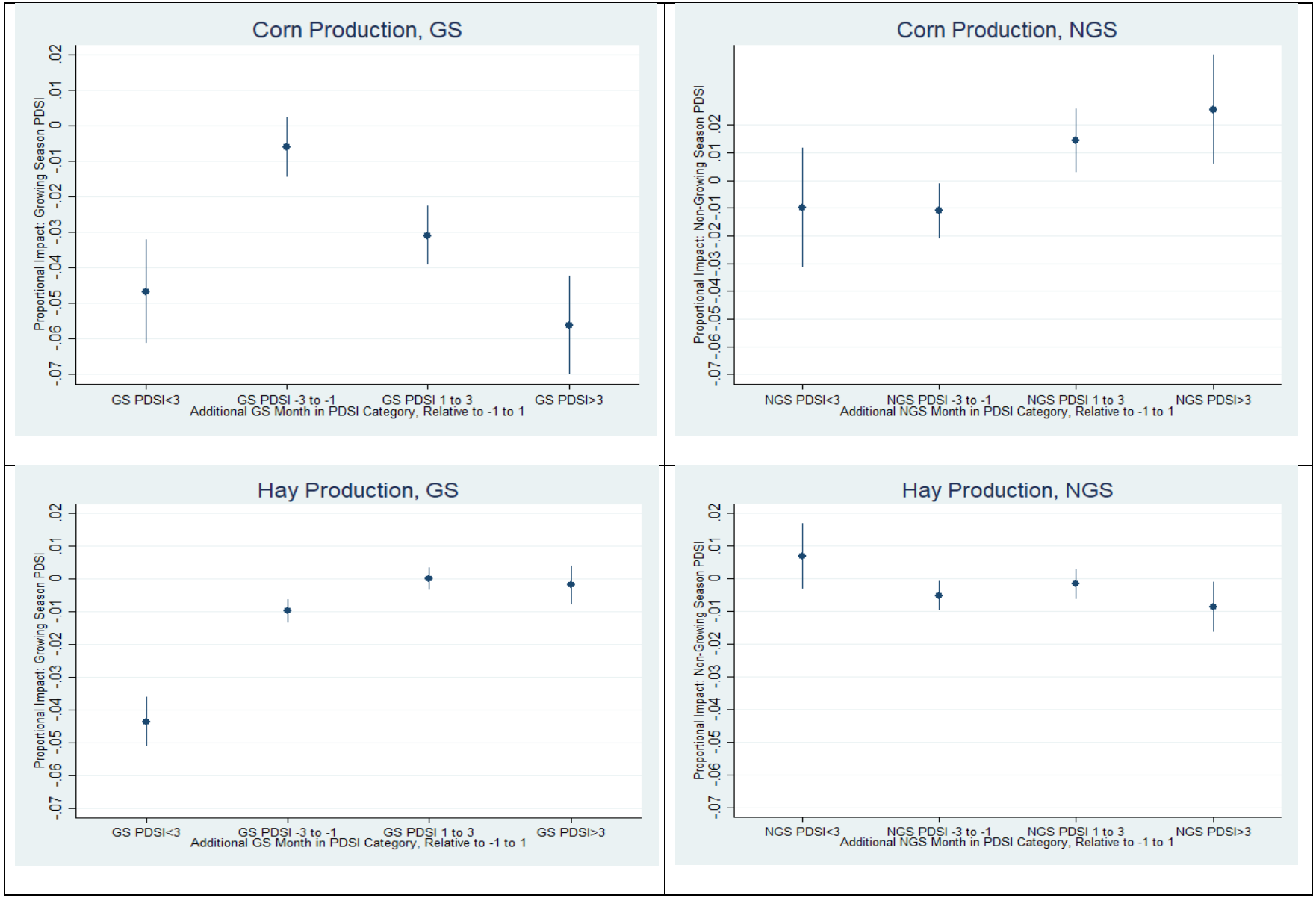


Figure 4: Proportional Drought Impacts on Total Production for Corn and Hay: Growing Season v. Non-Growing Season

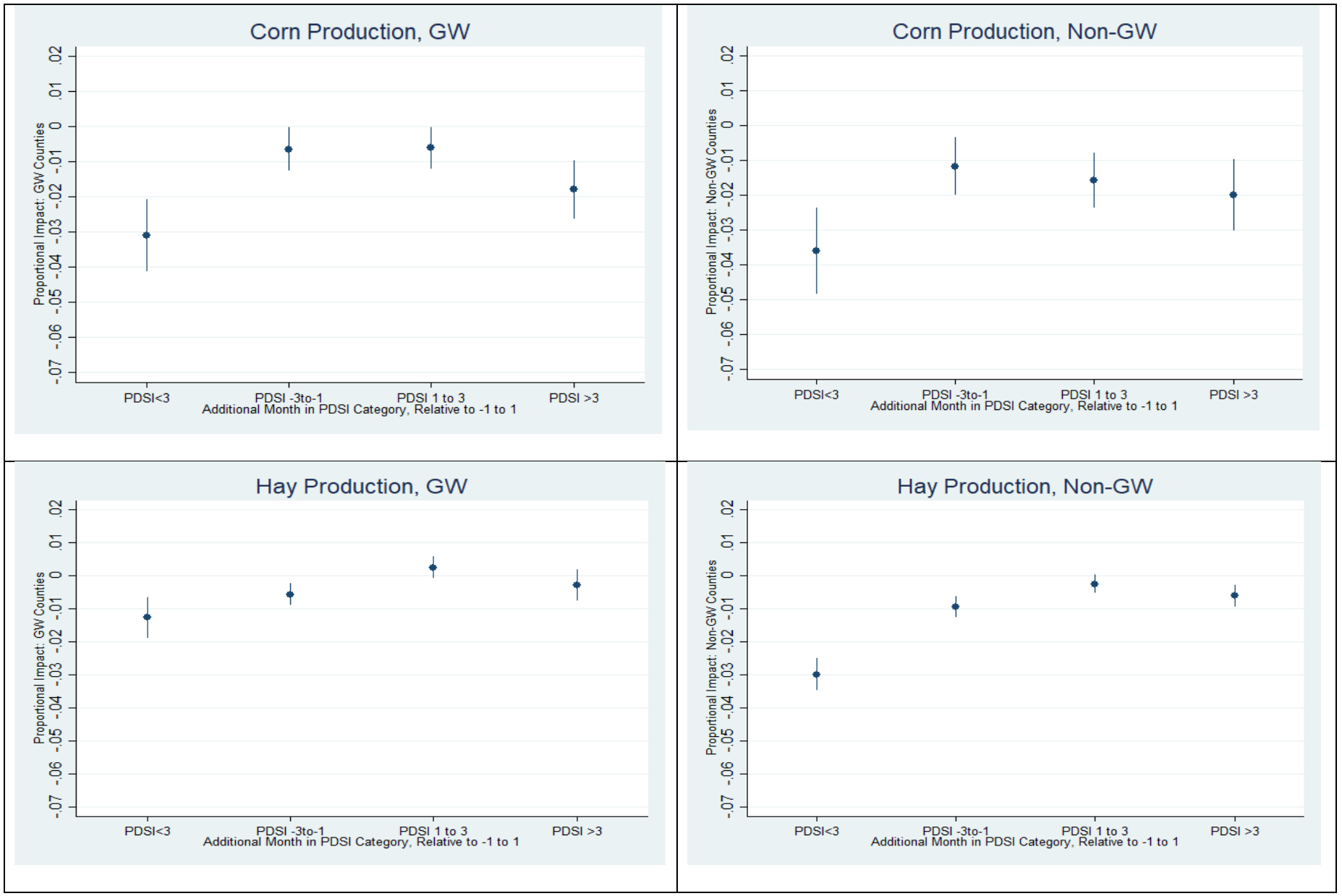


Figure 5: Proportional Drought Impacts on Total Production for Corn and Hay: Groundwater dependent versus non-groundwater dependent.

Economy-Wide impacts

Next, we turn to evaluating the impact of drought on other economic sectors. Importantly, the impacts presented below reflect the total effect of the drought on each sector. This includes the direct, as well as those associated with shocks to both backward and forward industries (indirect and induced). Figure 6 presents drought impacts on wages across all sectors in our study. The coefficient for moderate drought conditions was statistically significant at the 10% level. The results suggest that total wages increase during periods of moderate drought. Specifically, each additional month of moderate drought conditions increases total wages by approximately 0.2 percent. Alternatively, each month of extreme wet conditions reduces total wages by approximately 0.3 percent. We note however, that the impact on total wages masks important nuances in that some sectors experience increased wages while other sectors experience decreased wages. We explore these nuances below.

The impact of drought on total employment across all sectors is presented in Figure 6. We find that an additional month of moderate drought increases total employment by approximately 0.2 percent. On the other hand, extreme wet conditions do not statistically significantly impact total employment. Higher temperatures have a positive (and diminishing) effect on total employment, whereas more precipitation has a negative effect on total employment.

The impact of drought on the number of establishments present across all sectors is presented in the right-hand side panel of Figure 7. Again, moderate drought is positive and statistically significantly correlated with establishment counts. Alternatively, an additional month of extreme wet conditions is negatively correlated with establishments. Higher temperatures have a positive (and diminishing) effect on the overall number of establishments, whereas more precipitation has a negative effect on the overall number of establishments. Full results are presented in Tables 3-5 below.

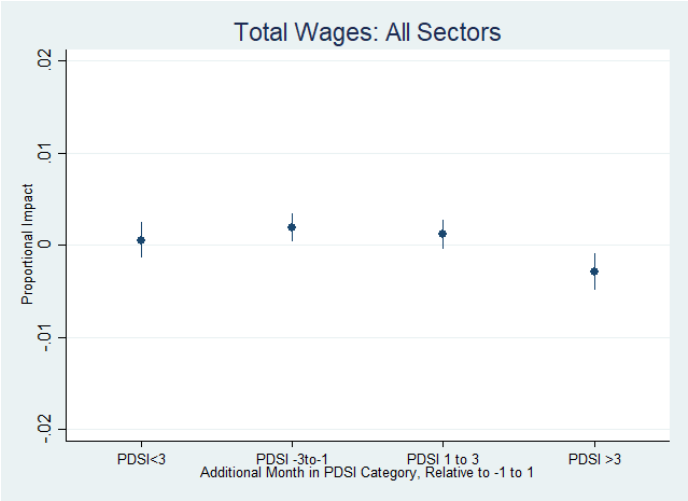


Figure 6: Proportional Drought Impacts on Total Wages across all sectors of the economy measured in the NAICS codes.

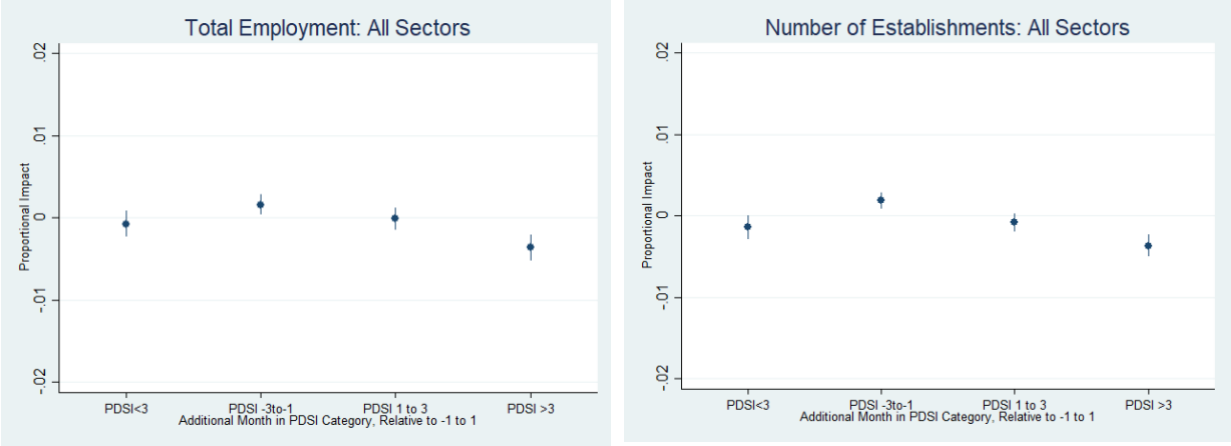


Figure 7: Proportional Drought Impacts on Total Employment and Number of Establishments across all sectors of the economy measured in the NAICS codes.

Sector-Level Analysis

The results in the previous section present the impacts of drought on wages, number of establishments, and employment across all economic sectors. However, this aggregate analysis masks some important nuances. In the following section, we evaluate drought impacts on wages, number of establishments, and employment for specific sectors of the economy. We find that drought has negative impacts on some sectors and positive impacts on other sectors.

Total Wages

First, we look at total wages for specific sectors. The results are presented in Table 3. Column 1 presents the aggregate impacts of drought across all economic sectors. The first four coefficients, the coefficients on the PDSI bins, are the same coefficients that are presented in Figure 6. The table also displays coefficient estimates on temperature, temperature squared, precipitation and precipitation squared. Columns 2-9 estimate the model for specific sectors. The results indicate that an additional month of extreme drought decreases agricultural, fishing, and hunting wages by 0.5 percent and recreation and entertainment wages by 0.6. In contrast, an additional month of extreme drought increases utility wages by 0.7 percent. The sum of these coefficients explains why aggregate wages (Column 1) are not statistically significantly affected by extreme drought conditions.

Several possible explanations exist for these findings. While it is reasonable that drought would negatively impact agricultural, fishing, and hunting wages and recreation and entertainment wages, it

is somewhat surprising that drought would positively impact utility wages. One possible explanation is that drought conditions cause business owners to use more municipal water, which would result in greater demand for the services utilities provide.

Next, Table 4 presents the impacts of drought on employment across several economic sectors. The results are qualitatively similar to the impacts on wages and substantiate the hypothesis that drought reduces employment in agriculture, fishing, and hunting and recreation and entertainment, which reduces wages. The finding that wages increases in some sectors during periods of drought is consistent with Branco and Feres (2020) who find that drought increases employment in non-agricultural sectors – albeit in a developing country context.

Table 5 presents the impacts of drought on the number of establishments across several economic sectors. The impact of drought on establishment numbers is slightly different from the impact of drought on wages and employment. We find that the number of recreation and entertainment, service, and trade establishments are negatively correlated with extreme drought conditions, but the standard errors are relatively large for service and trade. In contrast, moderate drought conditions are positively correlated with the number of agricultural, fishing, and hunting, other, service, and trade establishments, while extreme wet conditions are negatively correlated with recreational and entertainment establishments, manufacturing establishments, service establishments, and trade establishments.

Table 3: Drought Impact on Total Wages: Economy-Wide and by Major Economic Sector

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	**Ag, Fishing Hunting**	**Recreation Entertainment**	**Education Health**	**Manufacturing**	**Other**	**Service**	**Trade**	**Utilities**
PDSI <- 3	0.000532	-0.00542**	-0.00587**	-4.01e-05	0.00186	0.000413	0.000550	3.31e-05	0.00726***
	(0.000987)	(0.00262)	(0.00293)	(0.00275)	(0.00258)	(0.00259)	(0.00198)	(0.00134)	(0.00228)
PDSI between -3 and -1	0.00193**	0.00195	-0.00116	0.00258	0.00245	0.0127***	0.00286*	0.00165*	0.00476**
	(0.000766)	(0.00181)	(0.00204)	(0.00215)	(0.00170)	(0.00232)	(0.00149)	(0.000882)	(0.00194)
PDSI between 1 and 3	0.00118	0.000340	-0.00229	0.00236	0.00439**	0.00846***	-0.00183	-0.000218	-0.000316
	(0.000822)	(0.00190)	(0.00248)	(0.00219)	(0.00182)	(0.00283)	(0.00147)	(0.00101)	(0.00199)
PDSI > 3	-0.00289***	-0.00147	-0.00490*	0.00326	-0.000846	-0.00976**	-0.00697***	-0.00434***	-0.00539**
	(0.00101)	(0.00220)	(0.00295)	(0.00262)	(0.00226)	(0.00413)	(0.00175)	(0.00125)	(0.00233)
Annual average temperature	0.0496***	0.103***	0.0494	0.00684	0.000779	-0.0398	0.0336	0.0384***	0.0597**
	(0.0135)	(0.0275)	(0.0366)	(0.0289)	(0.0253)	(0.0271)	(0.0207)	(0.0138)	(0.0274)
Annual average temperature squared	-0.00135***	-0.00231***	-0.00128	0.000200	0.000221	0.00115*	-0.00150***	-0.000983***	-0.00128*
	(0.000345)	(0.000696)	(0.000908)	(0.000741)	(0.000659)	(0.000681)	(0.000540)	(0.000364)	(0.000688)

Precipitation	-5.47e-05***	0.000104*	-6.50e-05	-2.70e-05	-7.19e-06	-0.000133	-6.67e-05*	-4.65e-05**	-1.75e-05
	(1.59e-05)	(5.33e-05)	(6.43e-05)	(5.00e-05)	(4.04e-05)	(8.32e-05)	(3.62e-05)	(2.07e-05)	(4.77e-05)
Precipitation squared	1.38e-08***	-5.06e-08***	3.34e-08	1.07e-08	1.01e-08	5.15e-08	2.39e-08**	1.31e-08**	-5.69e-09
	(4.94e-09)	(1.76e-08)	(2.17e-08)	(1.39e-08)	(1.15e-08)	(3.51e-08)	(1.10e-08)	(6.37e-09)	(1.58e-08)
Constant	2.912***	-1.672***	-2.031***	-1.566***	1.632***	-3.334***	1.611***	1.837***	0.949***
	(0.133)	(0.282)	(0.377)	(0.291)	(0.253)	(0.325)	(0.207)	(0.131)	(0.281)
County fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	32,148	23,504	19,805	21,441	26,994	16,031	31,354	31,790	29,939
R-squared	0.762	0.476	0.478	0.854	0.209	0.891	0.281	0.392	0.361
Number of Counties	871	860	718	840	836	871	871	870	869

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Drought Impact on Employment: Economy-Wide and by Major Economic Sector

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	**Ag, Fishing Hunting**	**Recreation Entertainment**	**Education Health**	**Manufacturing**	**Other**	**Service**	**Trade**	**Utilities**
PDSI <- 3	-0.000746	-0.00500*	-0.00634**	-0.00117	-0.00135	-7.95e-05	-0.000567	0.000280	0.00318
	(0.000802)	(0.00257)	(0.00258)	(0.00235)	(0.00226)	(0.00239)	(0.00170)	(0.000972)	(0.00197)
PDSI between -3 and -1	0.00163***	0.00160	-0.000915	0.00144	0.00196	0.0101***	0.00257*	0.00151**	0.00382**
	(0.000609)	(0.00176)	(0.00181)	(0.00185)	(0.00147)	(0.00216)	(0.00134)	(0.000682)	(0.00166)
PDSI between 1 and 3	-0.000112	0.000455	-0.00246	0.00219	0.00210	0.00382	-0.00177	-0.000813	-0.00178
	(0.000667)	(0.00184)	(0.00217)	(0.00191)	(0.00156)	(0.00265)	(0.00130)	(0.000802)	(0.00171)
PDSI > 3	-0.00360***	0.000813	-0.00385	0.00410*	-0.00322*	-0.00597	-0.00691***	-0.00363***	-0.00704***
	(0.000802)	(0.00216)	(0.00249)	(0.00221)	(0.00194)	(0.00365)	(0.00149)	(0.000955)	(0.00200)
Annual average temperature	0.0543***	0.0760***	0.0525	-0.00387	0.0254	-0.0724***	0.0280	0.0190*	0.0916***
	(0.0108)	(0.0262)	(0.0325)	(0.0244)	(0.0216)	(0.0257)	(0.0181)	(0.0108)	(0.0237)
Annual average temperature squared	-0.00152***	-0.00167**	-0.00148*	0.000429	-0.000508	0.00185***	-0.00136***	-0.000559*	-0.00219***
	(0.000278)	(0.000666)	(0.000811)	(0.000620)	(0.000568)	(0.000627)	(0.000472)	(0.000288)	(0.000598)

Precipitation	-5.39e-05***	5.54e-05	-5.08e-05	-6.25e-05	-1.98e-05	-0.000133*	-6.24e-05*	-5.01e-05***	-1.80e-05
	(1.41e-05)	(4.92e-05)	(5.79e-05)	(4.51e-05)	(3.59e-05)	(7.28e-05)	(3.21e-05)	(1.67e-05)	(3.90e-05)
Precipitation squared	1.40e-08***	-2.88e-08*	2.57e-08	1.99e-08	1.18e-08	3.88e-08	2.09e-08**	1.51e-08***	-4.56e-09
	(4.29e-09)	(1.56e-08)	(1.96e-08)	(1.32e-08)	(1.00e-08)	(2.94e-08)	(9.82e-09)	(5.32e-09)	(1.22e-08)
Constant	9.859***	5.787***	5.649***	6.186***	8.287***	4.413***	8.874***	9.200***	7.364***
	(0.105)	(0.267)	(0.330)	(0.248)	(0.213)	(0.312)	(0.179)	(0.102)	(0.242)
County fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	32,148	23,504	19,805	21,441	26,994	16,023	31,354	31,790	29,938
R-squared	0.275	0.171	0.232	0.768	0.038	0.868	0.369	0.317	0.097
Number of Counties	871	860	718	840	836	871	871	870	869

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Drought Impact on Number of Establishments: Economy-Wide and by Major Economic Sector

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	**Ag, Fishing Hunting**	**Recreation Entertainment**	**Education Health**	**Manufacturing**	**Other**	**Service**	**Trade**	**Utilities**
PDSI <- 3	-0.00139*	-0.000428	-0.00504***	-0.00152	-0.000859	-0.000452	-0.00214*	-0.00170*	-0.000333
	(0.000748)	(0.00177)	(0.00165)	(0.00182)	(0.00134)	(0.00185)	(0.00112)	(0.000866)	(0.00130)
PDSI between -3 and -1	0.00190***	0.00300**	-0.000589	-0.00166	0.000510	0.00696***	0.00196***	0.00134**	0.00189*
	(0.000513)	(0.00131)	(0.00107)	(0.00135)	(0.000982)	(0.00171)	(0.000738)	(0.000594)	(0.00104)
PDSI between 1 and 3	-0.000778	0.00249*	-0.00224*	-0.00225	0.000144	0.00670***	-0.000599	-0.000517	-0.00235**
	(0.000561)	(0.00146)	(0.00133)	(0.00137)	(0.00102)	(0.00185)	(0.000739)	(0.000660)	(0.00108)
PDSI > 3	-0.00366***	0.00587***	-0.00301**	0.00210	-0.00249*	0.00277	-0.00436***	-0.00293***	-0.00789***
	(0.000698)	(0.00166)	(0.00152)	(0.00143)	(0.00129)	(0.00311)	(0.000946)	(0.000761)	(0.00132)
Annual average temperature	0.0728***	0.0587***	0.0296*	-0.0114	0.0109	-0.114***	0.0690***	0.0470***	0.122***
	(0.00840)	(0.0180)	(0.0162)	(0.0159)	(0.0158)	(0.0213)	(0.0111)	(0.00887)	(0.0145)
Annual average temperature squared	-0.00220***	-0.000753*	-0.00112***	0.000476	-0.000505	0.00273***	-0.00235***	-0.00139***	-0.00321***
	(0.000219)	(0.000435)	(0.000413)	(0.000405)	(0.000406)	(0.000525)	(0.000284)	(0.000234)	(0.000361)

Precipitation	-7.74e-05***	6.84e-05**	-5.75e-05**	-0.000149***	-0.000137***	-0.000210***	2.74e-05	-4.81e-05***	-3.66e-05
	(1.21e-05)	(3.32e-05)	(2.67e-05)	(3.47e-05)	(2.45e-05)	(5.77e-05)	(2.04e-05)	(1.27e-05)	(2.67e-05)
Precipitation squared	2.02e-08***	-9.74e-09	1.12e-08	4.79e-08***	4.59e-08***	7.87e-08***	-4.79e-09	1.57e-08***	5.98e-09
	(3.81e-09)	(9.28e-09)	(7.36e-09)	(1.21e-08)	(7.67e-09)	(2.35e-08)	(5.66e-09)	(3.53e-09)	(9.41e-09)
Constant	6.526***	2.573***	2.784***	3.092***	4.278***	3.447***	5.421***	5.863***	4.091***
	(0.0822)	(0.196)	(0.165)	(0.164)	(0.158)	(0.257)	(0.112)	(0.0849)	(0.153)
County fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	32,189	27,039	22,685	25,072	28,783	16,279	31,787	32,061	30,932
R-squared	0.302	0.329	0.260	0.836	0.030	0.828	0.204	0.426	0.236
Number of Counties	871	869	834	867	863	871	871	871	871

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin. *** p<0.01, ** p<0.05, * p<0.1

Sub-Sector Specific Analysis: Agriculture

In this subsection, we further decompose the impact of drought on wages, employment, and number of establishments for specific agricultural sectors including livestock, crop production, and agricultural supply. The results for wages, employment, and number of establishments are presented in Tables 6-8 respectively. The results overwhelmingly indicate that extreme drought negatively impacts the agricultural economy. An additional month of extreme drought decreases agricultural supply wages by 1.3 percent. Correspondingly, an additional month of extreme drought decreases livestock and agricultural supply employment by 0.6 and 1.2 percent, respectively. Finally, an additional month of extreme drought decreases the number of agricultural supply establishments by 0.9 percent. However, livestock and crop production establishments are positively affected by extreme wet conditions. Overall, drought appears to significantly impact most agricultural sectors, even putting some out of business, with the effects on livestock production being especially important for states such as Colorado. Unfortunately, we cannot further disaggregate these into small and large businesses.

Table 6: Drought Impacts on Total Wages: Agricultural

	(1) **Livestock**	**(2)** **Crop Production**	**(3)** **Agricultural Supply**
PDSI <- 3	-0.00306 (0.00329)	-0.00270 (0.00344)	-0.0135*** (0.00434)
PDSI between -3 and -1	-0.00283 (0.00218)	0.00189 (0.00259)	0.000635 (0.00313)
PDSI between 1 and 3	0.000495 (0.00234)	0.000598 (0.00288)	-0.00572* (0.00331)
PDSI > 3	-0.00276 (0.00299)	-0.00388 (0.00330)	-0.00802** (0.00367)
Annual average temperature	0.0670** (0.0279)	0.183*** (0.0382)	0.200*** (0.0444)

Annual average temperature squared	-0.00137* (0.000700)	-0.00391*** (0.000990)	-0.00470*** (0.00110)
Precipitation	-3.02e-05 (6.16e-05)	6.05e-05 (7.04e-05)	-6.78e-05 (0.000101)
Precipitation squared	3.25e-08 (2.12e-08)	-6.10e-09 (2.05e-08)	8.90e-09 (3.80e-08)
Constant	-1.865*** (0.304)	-2.967*** (0.379)	-3.304*** (0.467)
County fixed effects	yes	yes	yes
Year fixed effects	yes	yes	yes
Observations	18,117	13,691	15,351
R-squared	0.395	0.416	0.298
Number of Counties	777	658	745

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Table 7: Drought Impacts on Employment: Agricultural

	(1) Livestock	(2) Crop Production	(3) Agricultural Supply
PDSI <- 3	-0.00641**	-0.00357	-0.0122***
	(0.00315)	(0.00334)	(0.00418)
PDSI between -3 and -1	-0.00300	0.000916	7.15e-05
	(0.00211)	(0.00260)	(0.00293)
PDSI between 1 and 3	0.000718	-0.000155	-0.00346
	(0.00225)	(0.00280)	(0.00303)
PDSI > 3	-0.000857	-0.00211	-0.00695*
	(0.00292)	(0.00324)	(0.00358)
Annual average temperature	0.0765***	0.192***	0.156***
	(0.0272)	(0.0372)	(0.0417)
Annual average temperature squared	-0.00158**	-0.00402***	-0.00374***
	(0.000680)	(0.000958)	(0.00103)
Precipitation	-5.56e-05	0.000100	-9.83e-05
	(6.04e-05)	(7.15e-05)	(9.10e-05)
Precipitation squared	3.88e-08*	-1.41e-08	1.59e-08
	(2.11e-08)	(2.10e-08)	(3.24e-08)
Constant	5.148***	4.111***	4.424***
	(0.297)	(0.372)	(0.443)
County fixed effects	yes	yes	yes

Year fixed effects	yes	yes	yes
Observations	18,117	13,691	15,351
R-squared	0.091	0.101	0.235
Number of Counties	777	658	745

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Table 8: Drought Impacts on Number of Establishments: Agricultural

	(1) **Livestock**	**(2)** **Crop Production**	**(3)** **Agricultural Supply**
PDSI <- 3	0.000432 (0.00206)	0.000119 (0.00218)	-0.00931*** (0.00249)
PDSI between -3 and -1	0.00133 (0.00152)	0.00277 (0.00182)	-0.000889 (0.00178)
PDSI between 1 and 3	0.00372** (0.00169)	0.000837 (0.00205)	-0.000992 (0.00200)
PDSI > 3	0.00587*** (0.00210)	0.00615*** (0.00236)	-0.00265 (0.00232)
Annual average temperature	0.0173 (0.0184)	0.132*** (0.0261)	0.106*** (0.0249)

Annual average temperature squared	-3.81e-05 (0.000455)	-0.00226*** (0.000651)	-0.00247*** (0.000609)
Precipitation	-1.07e-05 (4.08e-05)	0.000122*** (4.71e-05)	-9.99e-05** (4.89e-05)
Precipitation squared	3.00e-08** (1.35e-08)	-9.34e-10 (1.40e-08)	3.50e-08** (1.57e-08)
Constant	2.093*** (0.206)	0.776*** (0.268)	1.992*** (0.264)
County fixed effects	yes	yes	yes
Year fixed effects	yes	yes	yes
Observations	21,161	17,287	20,272
R-squared	0.308	0.289	0.331
Number of Counties	851	812	825

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Sub-Sector Specific Analysis: Recreation, Entertainment, and Travel

In this subsection, we continue to further disaggregate the impact of drought on wages, employment, and number of establishments for specific sectors including recreation, entertainment and travel. The results for wages, employment, and number of establishments are presented in Tables 9-11 respectively. In contrast to agricultural sectors, we find that drought conditions are statistically uncorrelated with fishing wages, employment, and number of establishments. However, this is likely due to the small number of fishing establishments we observe in our data.

On the other hand, all three measures for recreation and entertainment are negatively impacted by extreme drought conditions, which could be driven by lower snowpack during the winter months, low river levels during the summer, or increased fire severity during the summer. For example, an additional month of extreme drought decreases recreation and entertainment wages by 0.59 percent. Moderate drought is uncorrelated with recreational and entertainment wages, employment, and establishments.

Finally, an additional month of extreme drought increases travel wages by 0.3 percent while an additional month of moderate drought increases travel wages by 0.5 percent on average. Results are similar for travel employment and establishments. Overall, drought appears to negatively impact the recreation and entertainment sectors, which again is especially important for states such as Colorado that have large tourism and outdoor industries.

Table 9: Drought Impacts on Total Wages: Recreation, Entertainment, and Travel

	(1) Fish	(3) Recreation Entertainment	(3) Travel Accommodation
PDSI <- 3	0.00593	-0.00587**	0.00289*
	(0.0255)	(0.00293)	(0.00159)
PDSI between -3 and -1	0.0130	-0.00116	0.00524***
	(0.0124)	(0.00204)	(0.00121)
PDSI between 1 and 3	0.0123	-0.00229	0.000133
	(0.0143)	(0.00248)	(0.00117)
PDSI > 3	-0.0144	-0.00490*	-0.00339**
	(0.0207)	(0.00295)	(0.00153)
Annual average temperature	0.249	0.0494	0.0380*
	(0.269)	(0.0366)	(0.0199)
Annual average temperature squared	-0.00459	-0.00128	-0.00133***
	(0.00589)	(0.000908)	(0.000499)
Precipitation	0.000172	-6.50e-05	2.14e-06
	(0.000239)	(6.43e-05)	(3.10e-05)
Precipitation squared	-3.40e-08	3.34e-08	8.41e-09
	(4.28e-08)	(2.17e-08)	(9.38e-09)
Constant	-3.377	-2.031***	-0.0111
	(2.949)	(0.377)	(0.200)
County fixed effects	yes	yes	yes

Year fixed effects	yes	yes	yes
Observations	951	19,805	27,737
R-squared	0.096	0.478	0.743
Number of Counties	62	718	863

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Table 10: Drought Impacts on Number Employed: Recreation, Entertainment, and Travel

	(1) **Fish**	**(2)** **Recreation Entertainment**	**(3)** **Travel Accommodation**
PDSI <- 3	-0.00668 (0.0216)	-0.00634** (0.00258)	0.00324** (0.00139)
PDSI between -3 and -1	0.0182 (0.0127)	-0.000915 (0.00181)	0.00443*** (0.00102)
PDSI between 1 and 3	0.0117 (0.0142)	-0.00246 (0.00217)	-0.000125 (0.00103)
PDSI > 3	-0.00977 (0.0191)	-0.00385 (0.00249)	-0.00208 (0.00131)
Annual average temperature	0.139 (0.226)	0.0525 (0.0325)	0.00464 (0.0168)

Annual average temperature squared	-0.00195 (0.00527)	-0.00148* (0.000811)	-0.000413 (0.000422)
Precipitation	0.000124 (0.000190)	-5.08e-05 (5.79e-05)	4.10e-06 (2.68e-05)
Precipitation squared	-2.06e-08 (3.46e-08)	2.57e-08 (1.96e-08)	5.88e-09 (8.08e-09)
Constant	4.451* (2.308)	5.649*** (0.330)	8.003*** (0.169)
County fixed effects	yes	yes	yes
Year fixed effects	yes	yes	yes
Observations	951	19,805	27,737
R-squared	0.330	0.232	0.524
Number of Counties	62	718	863

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Table 11: Drought Impacts on Number of Establishments: Recreation, Entertainment, and Travel

	(1) Fish	(2) Recreation Entertainment	(3) Travel Accommodation
PDSI <- 3	-8.90e-05	-0.00504***	0.00316***
	(0.00745)	(0.00165)	(0.000944)
PDSI between -3 and -1	0.0118***	-0.000589	0.00287***
	(0.00454)	(0.00107)	(0.000669)
PDSI between 1 and 3	0.00978*	-0.00224*	0.000267
	(0.00511)	(0.00133)	(0.000746)
PDSI > 3	-0.00682	-0.00301**	-0.000401
	(0.00814)	(0.00152)	(0.000927)
Annual average temperature	-0.00544	0.0296*	-0.0205**
	(0.0560)	(0.0162)	(0.00935)
Annual average temperature squared	0.000592	-0.00112***	0.000426*
	(0.00119)	(0.000413)	(0.000235)
Precipitation	0.000146	-5.75e-05**	5.54e-05***
	(9.27e-05)	(2.67e-05)	(1.90e-05)
Precipitation squared	-3.72e-08*	1.12e-08	-2.14e-09
	(2.06e-08)	(7.36e-09)	(5.83e-09)
Constant	3.010***	2.784***	4.764***
	(0.603)	(0.165)	(0.0976)

County fixed effects	yes	yes	yes
Year fixed effects	yes	yes	yes
Observations	2,320	22,685	28,046
R-squared	0.304	0.260	0.743
Number of Counties	232	834	871

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Health Impacts and Criminal Activity

In the following section we evaluate the impact of drought on public health and criminal activity. The results are presented in Tables 12 and 13, respectively. While the mechanisms driving the relationship between drought and agricultural production and the agricultural economy are clear, the mechanisms driving the relationship between drought and public health and criminal activity are less clear. Consequently, we find very little statistical relationship between drought and public health with the exception that an additional month of extreme wet conditions decreases the annual county-level incidence of heart disease by 0.5 percent. This could possibly be due to the decrease in agricultural production associated with drought, which could lower agricultural worker stress.

Similar to the impact on health outcomes, Table 13 indicates that drought and wet conditions are largely uncorrelated with annual criminal activity. We do find that an additional month of moderate drought is associated with a 0.4 and 0.3 percent reduction in simple assaults and property crime, respectively.

Table 12: Drought Impacts on Health Outcomes

	(1) **Opioids**	**(2)** **Alcohol**	**(3)** **Heart Disease**
PDSI <- 3	0.00430	-0.000818	-0.00504***
	(0.00553)	(0.0111)	(0.00118)
PDSI between -3 and -1	-0.000207	-0.0115	0.000206
	(0.00422)	(0.00863)	(0.000995)
PDSI between 1 and 3	0.00196	-0.0153	-0.00216*
	(0.00407)	(0.0104)	(0.00115)
PDSI > 3	-0.00334	-0.0163	-0.000810
	(0.00583)	(0.0124)	(0.00152)
Annual average temperature	-0.0814*	-0.130	-0.0187
	(0.0460)	(0.102)	(0.0119)

Annual average temperature squared	0.00128 (0.00109)	0.000550 (0.00233)	6.37e-05 (0.000276)
Precipitation	0.000113 (8.76e-05)	-0.000253 (0.000201)	-5.71e-05* (3.04e-05)
Precipitation squared	-4.58e-08* (2.70e-08)	8.20e-08 (6.96e-08)	5.06e-09 (9.16e-09)
County fixed effects	yes	yes	yes
Year fixed effects	yes	yes	yes
Observations	13,266	9,918	15,448
R-squared			0.766
Number of Counties	735	550	868

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Table 13: Drought Impacts on Criminal Activity

	(1) Aggravated Assault	(2) Simple Assault	(3) Property Crime	(4) Violent Crime
PDSI <- 3	-0.00396 (0.00337)	0.00474 (0.00323)	0.00150 (0.00218)	-0.00202 (0.00315)
PDSI between -3 and -1	-0.00379 (0.00245)	-0.00434* (0.00233)	-0.00292* (0.00163)	-0.00229 (0.00232)
PDSI between 1 and 3	-0.000999 (0.00295)	-0.000750 (0.00269)	-0.00141 (0.00183)	0.000385 (0.00270)
PDSI > 3	-0.000747 (0.00324)	-0.00261 (0.00311)	0.00231 (0.00212)	0.00101 (0.00304)
Annual average temperature	0.0425 (0.0318)	-0.0790*** (0.0282)	-0.0254 (0.0212)	0.0420 (0.0286)
Annual average temperature squared	-0.000996 (0.000762)	0.00243*** (0.000678)	0.000813 (0.000496)	-0.000873 (0.000678)
Precipitation	-1.54e-05 (5.95e-05)	3.69e-06 (5.40e-05)	1.56e-05 (3.53e-05)	1.55e-05 (5.50e-05)
Precipitation squared	1.06e-09 (1.51e-08)	-2.08e-08 (1.51e-08)	-1.04e-08 (1.02e-08)	-6.53e-09 (1.38e-08)
Constant	0.646* (0.346)	2.547*** (0.307)	7.715*** (0.236)	4.516*** (0.317)
County fixed effects	yes	yes	yes	yes

Year fixed effects	yes	yes	yes	yes
Observations	17,163	17,015	17,510	17,455
R-squared	0.019	0.168	0.124	0.017
Number of Counties	825	822	824	826

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Total Revenue, Total Taxes, and Insurance Claims and Payments

This section presents the relationship between months of drought and total revenue and total taxes (Tables 14 and 15). We find that an additional month of extreme drought increases total government revenue by 0.4 percent while an additional month of moderate drought increases total taxes by 0.3 percent. Moderately wet and extreme wet conditions are also positively associated with total government revenue and taxes.

While drought conditions reduce agricultural crop production, acres harvested, and yields, these impacts are likely offset by crop insurance payments. Not surprisingly, extreme drought is associated with increases in indemnity payments and policy counts by 10 and 7 percent, respectively (Table 15). Moderate drought increases indemnity payments and policy counts by 6.5 and 4.7 percent, respectively. These payments, which are not reflected in traditional analyses like IMPLAN, likely offset the negative agricultural production impacts associated with drought and help to explain the positive impact of drought on local government revenues. Interestingly, indemnity payments are also positively associated with extreme wet conditions, which may reflect the negative relationship between some crop yields and other events that are correlated with extreme wet conditions.

Table 14: Drought Impacts on Total Revenue and Total Taxes

	(1) **Total Revenue**	**(2)** **Total Taxes**
PDSI<-3	0.00416* (0.00234)	0.00112 (0.00261)
PDSI -3 to-1	2.42e-05 (0.00179)	0.00344** (0.00161)
PDSI 1 to 3	0.00312* (0.00183)	0.00171 (0.00171)
PDSI >3	0.00357** (0.00176)	0.00299* (0.00169)

Annual average temperature	-0.0325 (0.0208)	-0.0779*** (0.0243)
Annual average temperature squared	0.000675 (0.000581)	0.00172** (0.000665)
Precipitation	-1.93e-05 (3.67e-05)	-6.18e-05 (4.21e-05)
Precipitation squared	-2.94e-09 (9.34e-09)	1.47e-08 (1.18e-08)
Constant	8.994*** (0.199)	8.366*** (0.230)
Observations	8,189	8,186
R-squared	0.784	0.814
Number of fips	286	286

Robust standard errors in parentheses

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

Table 15: Drought Impacts on Insurance Liability and Indemnity Amounts and Counts of Indemnity Policies

	(1) Liability Amount	(2) Indemnity Amount	(3) Policy Count
PDSI<-3	0.000668	0.101***	0.0705***
	(0.00366)	(0.00681)	(0.00446)
PDSI -3 to-1	0.00265	0.0654***	0.0466***
	(0.00238)	(0.00455)	(0.00308)
PDSI 1 to 3	0.000905	0.00204	-0.00232
	(0.00282)	(0.00476)	(0.00325)
PDSI >3	-0.00743**	0.0127**	0.00698
	(0.00297)	(0.00631)	(0.00424)
Annual average temperature	-0.0440	-0.309***	-0.0643
	(0.0404)	(0.0717)	(0.0456)
Annual average temperature squared	0.00156	0.0114***	0.00487***
	(0.00101)	(0.00193)	(0.00123)
Precipitation	0.000657***	0.000303	0.000188
	(0.000190)	(0.000290)	(0.000193)
Precipitation squared	-1.74e-07*	4.12e-07***	2.99e-07***
	(9.72e-08)	(1.51e-07)	(1.01e-07)
Constant	14.16***	12.79***	2.557***
	(0.433)	(0.750)	(0.496)
Observations	14,701	13,984	13,984

R-squared	0.488	0.318	0.250
Number of fips	768	751	751

Robust standard errors in parentheses

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

Simulations

The estimates presented thus far correspond separate out the effects of marginal changes in precipitation and temperature, as well as the average impact of an additional month of drought conditions across a span of approximately 40 years and across the entire western US. In this section, we apply the methodology outlined in the Methodological Approach and Data Section to simulate the impact of specific drought years on particular counties. *The impacts presented reflect the combined effect of prolonged drought conditions, as well as contemporaneous weather conditions.* We present, as an example, the impacts for Otero County, Colorado associated with conditions experienced in 2012 and 2018. We chose Otero County as a representative agricultural county in Colorado, but the analysis could be applied to any county in our sample. Figures 8-10 display the inputs to the simulation model including the number of months in different drought PDSI categories during the growing and non-growing season as well as annual temperatures and precipitation for Otero County. For comparison, Figures 11-14 display the distribution of the moderate and extreme drought conditions across the western US for 2012 and 2018. We present the drought maps (Figures 11-14) simply as a reference to the broader drought conditions faced by the entire west during each year.

The results are presented in Tables 16-19. The first column of each table displays the output variable we are simulating. The second column of each table displays the estimated impact. The third column displays the t-statistic for the simulated impact. The fourth column indicates whether the estimate is significant at the 95% confidence level. The final two columns provide the lower and upper 95% confidence intervals. For example, our simulated results indicate the 2012 drought, precipitation, and temperature conditions reduced corn production in Otero County, CO by approximately 63 percent with a 95 percent confidence interval of 53-73 percent. On the other hand, Table 15 shows that the simulated impact of the 2018 drought did not statistically significantly impact corn production in Otero County. This is perhaps unsurprising as Figure 8 shows that growing season conditions were much less extreme in 2018 for Otero County.

While a reduction of 63 percent in corn production may seem large, this effect is in line with what producers self-reported during this period. For example, survey responses from dryland corn producers in the Arkansas Valley of Colorado reported an 87 percent reduction in yield (relative to expected) and a 68 percent reduction in harvested acres (relative to expected) (Goemans et al. (2013)). Hay, wheat, and sorghum were also dramatically impacted but not as much as corn production. Again, we also find that a sizable fraction of the production declines can be attributed to reduced acres harvested, indicating that farmers are responding on both the intensive and extensive margins.

The simulated corn production response to drought could be caused by several factors. First, corn crops may be more sensitive to changes in water supply than other crops. Second, farms that produce corn might have water rights that differ from farmers that produce other crops on average. While there are other possible factors, our analysis does not allow us to disentangle the mechanisms behind the declines in production.

We should also highlight several caveats to these projections. First, the models do not account for time varying factors other than drought, precipitation, and temperature. In particular, we cannot account for farm specific practices such as changes in irrigation strategies or crop choices. Second, the projections do not account for market specific shocks, such as a pandemic or recession. Finally, the projections cannot account for general equilibrium responses by farmers to past drought conditions, or to changes in the demand or competition in certain markets. In summary, these results should be considered the predicted impact of drought conditions, temperature, and precipitation in Otero County relative to average conditions in that county.

The tables also show the simulated impact of each drought year on the other outcome variables analyzed in the previous sections. For instance, the 2012 drought was associated with a reduction in overall employment, number of establishments, and wages, with results varying by sector. Perhaps most interesting is the 2012 drought is negatively associated with alcohol, opioid, and heart disease death rates in Otero County, but positively associated with simple assault and property crime rates. Drought can clearly be a stressor for farmers and workers whose income depends on the presence of water, which could cause increased aggression in the form of simple assaults.

An important finding is that the 2012 drought did not statistically impact employment in livestock sector (Table 18). Again, this could be caused by several factors. First, the timing estimates from the regression analysis show a positive relationship between employment in the livestock sector and temperature. Second, and more importantly, the results presented herein correspond to the short-term impacts associated with prolonged drought conditions. Drought impacts on the livestock sector are dynamic in nature, with substantial negative impacts unfolding over multiple years.

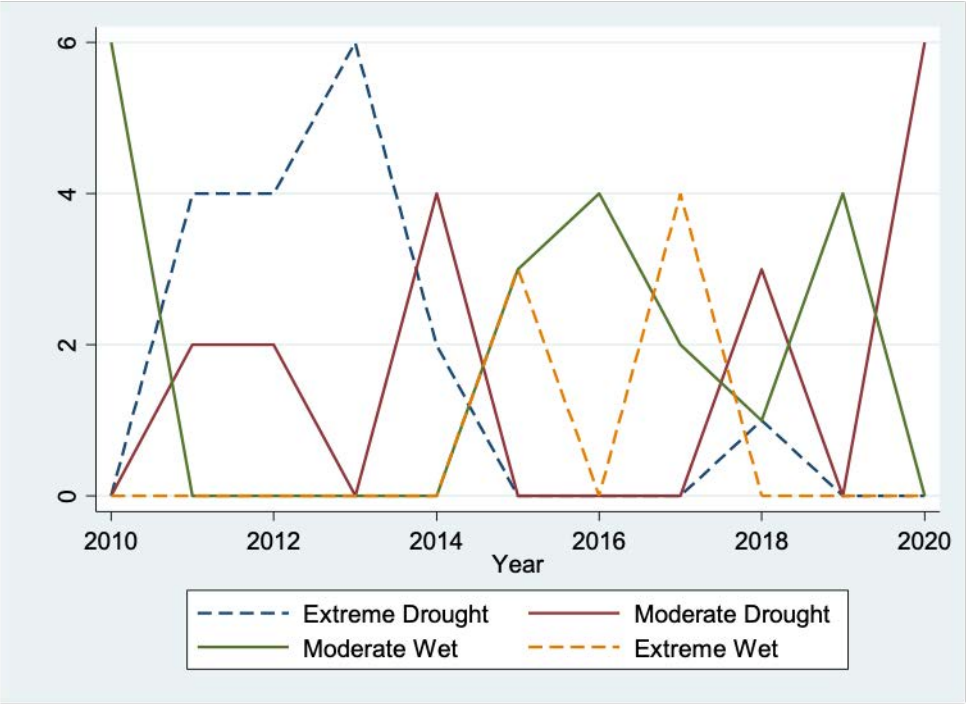


Figure 8: Number of months Otero County, CO experienced different drought conditions during the growing season from 2010-2020.

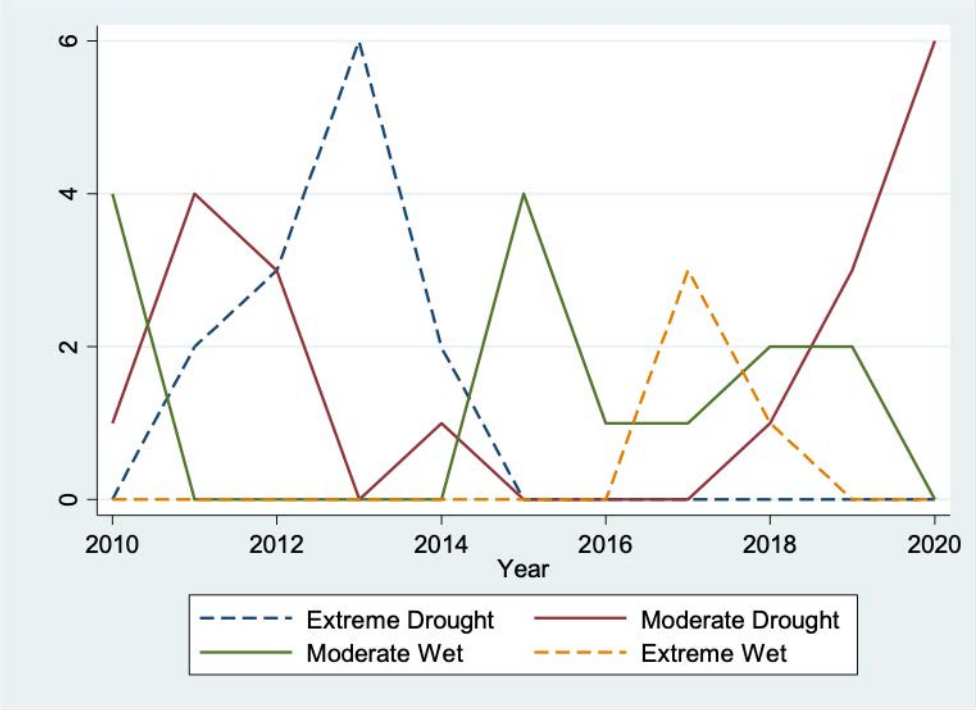
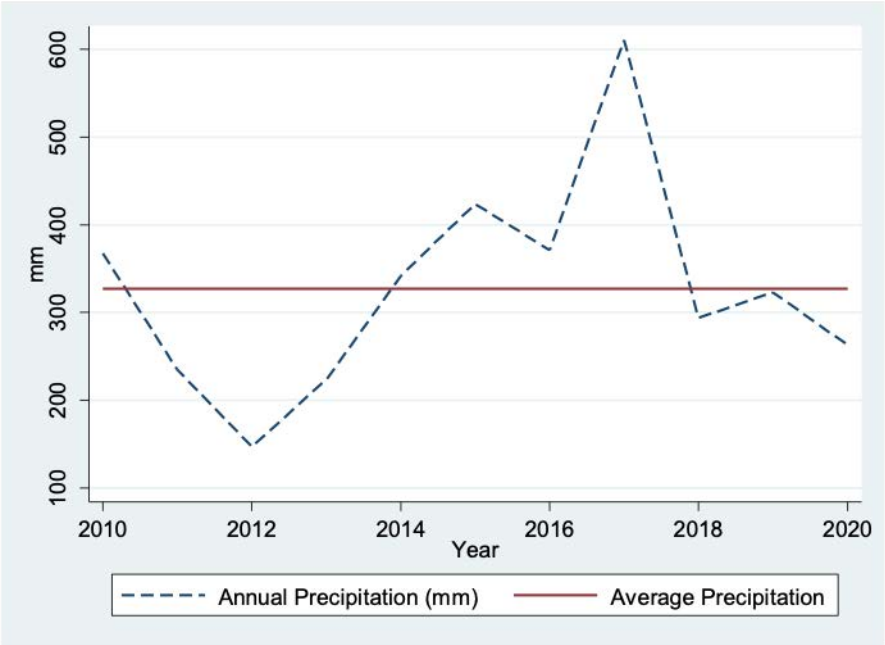


Figure 9: Number of months Otero County, CO experienced different drought conditions during the non-growing season from 2010-2020.



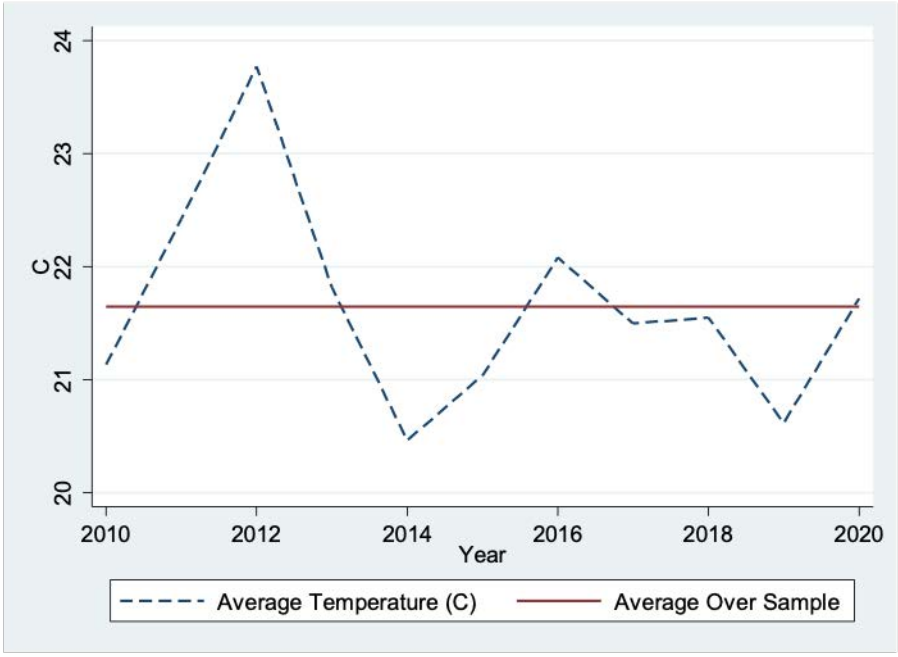


Figure 10: Average annual precipitation and temperature for Otero County, CO from 2010-2020.

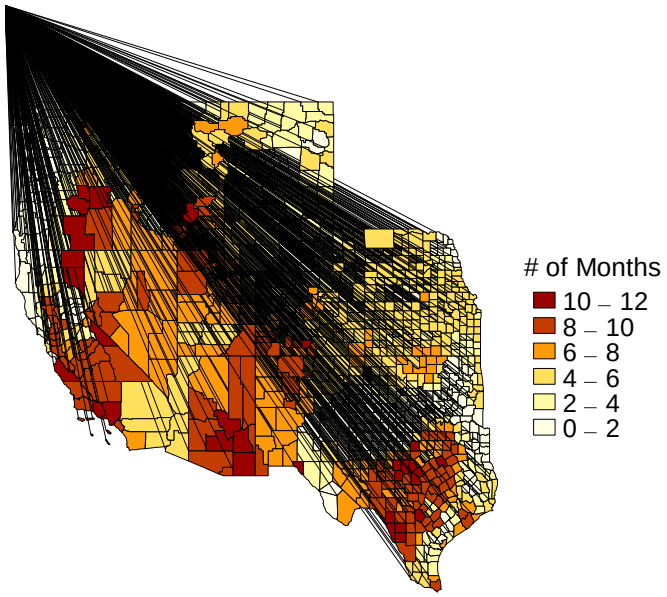


Figure 11: Number of months of Moderate Drought (-3<PDSI<-1) by county in 2012.

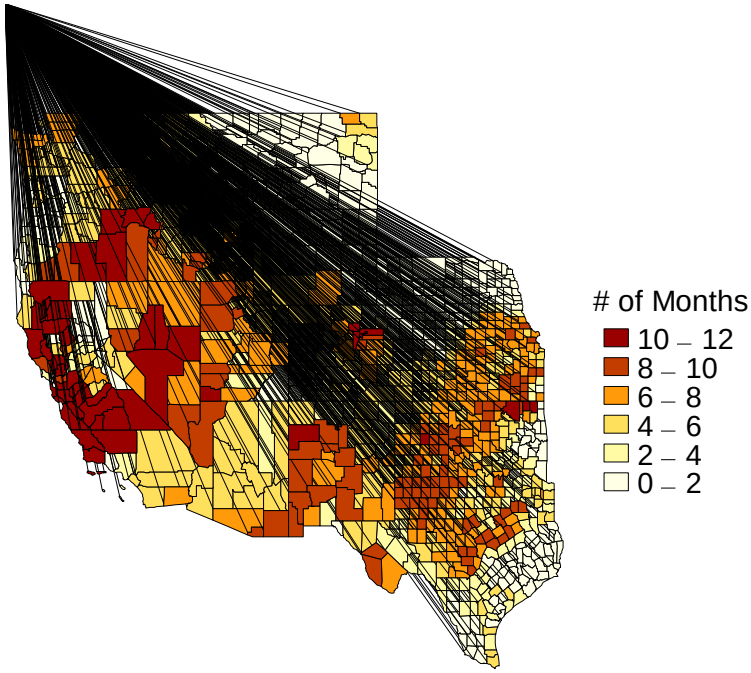


Figure 12: Number of months of Moderate Drought (-3<PDSI<-1) by county in 2018

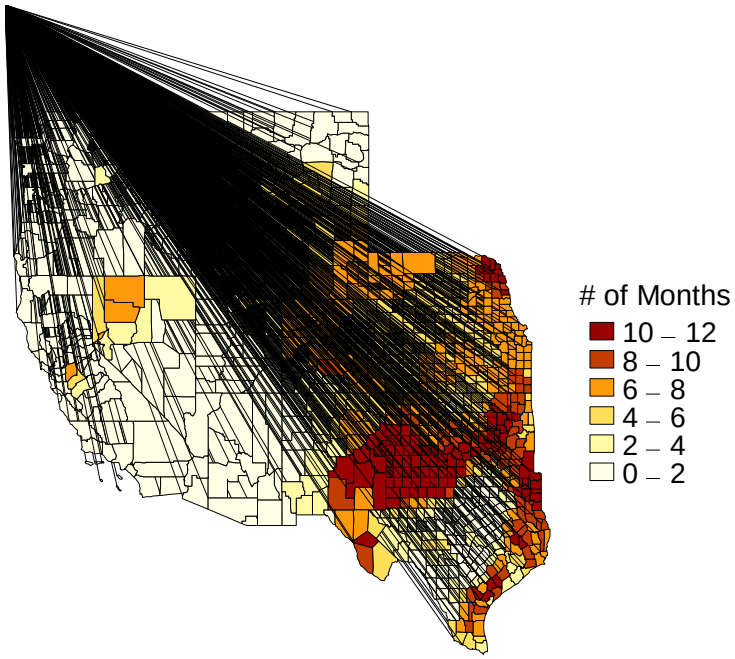


Figure 13: Number of months of Extreme Drought (PDSI<-3) by county in 2012

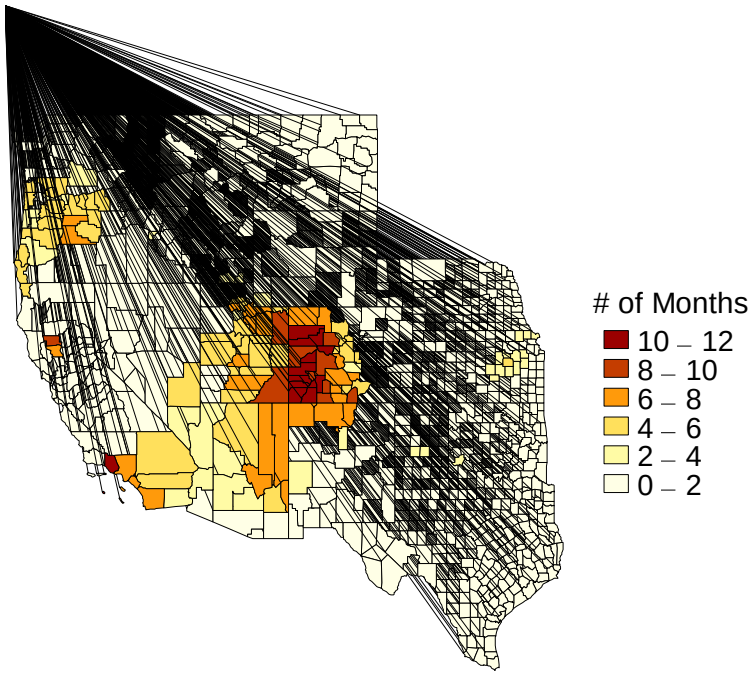


Figure 14: Number of months of Extreme Drought (PDSI<-3) by county in 2018

Table 16: Simulation of Proportional Impact of 2012 Drought on Otero County, Colorado

	Impact	Standard error	t	Significant	Lower 95% CI	Upper 95% CI
Agricultural Outcomes						
Corn Production	-0.63193	0.052504	-12.0359	Yes	-0.73484	-0.52902
Hay Production	-0.37348	0.025978	-14.3768	Yes	-0.42439	-0.32256
Wheat Production	-0.38478	0.037876	-10.1589	Yes	-0.45902	-0.31054
Sorghum Production	-0.269	0.058801	-4.57472	Yes	-0.38425	-0.15375
Corn Acres Harvested	-0.23426	0.043438	-5.39294	Yes	-0.3194	-0.14912
Hay Acres Harvested	-0.06466	0.018946	-3.41279	Yes	-0.10179	-0.02752
Wheat Acres Harvested	-0.24198	0.032134	-7.53021	Yes	-0.30496	-0.179
Sorghum Acres Harvested	0.228137	0.054662	4.173573	Yes	0.120999	0.335275
Employment						
Overall	-0.02798	0.008568	-3.26516	Yes	-0.04477	-0.01118
Ag Fish and Hunt	-0.03303	0.024741	-1.33494	No	-0.08152	0.015465
Education and Health	0.039157	0.023259	1.683551	No	-0.00643	0.084744
Manufacturing	-0.00021	0.022149	-0.00932	No	-0.04362	0.043206
Recreation and Entertainment	-0.05728	0.026004	-2.20287	Yes	-0.10825	-0.00632
Services	-0.06645	0.016976	-3.91462	Yes	-0.09973	-0.03318
Retail and Wholesale	0.001723	0.010343	0.166596	No	-0.01855	0.021995
Utilities and Construction	0.025076	0.020081	1.248728	No	-0.01428	0.064434
Establishments						
Overall	-0.05695	0.007636	-7.45752	Yes	-0.07192	-0.04198
Ag Fish and Hunt	0.050945	0.015417	3.304443	Yes	0.020727	0.081162

Education and Health	0.04069	0.016088	2.529183	Yes	0.009157	0.072222
Manufacturing	-0.0148	0.013811	-1.0714	No	-0.04187	0.012273
Recreation and Entertainment	-0.06934	0.015125	-4.58442	Yes	-0.09899	-0.0397
Services	-0.10747	0.011125	-9.66069	Yes	-0.12928	-0.08567
Retail and Wholesale	-0.03756	0.008893	-4.22312	Yes	-0.05499	-0.02013
Utilities and Construction	-0.03668	0.012197	-3.00699	Yes	-0.06058	-0.01277
Wage Bill						
Overall	-0.0157	0.010562	-1.48649	No	-0.0364	0.005001
Ag Fish and Hunt	-0.04395	0.025816	-1.70223	No	-0.09455	0.006655
Education and Health	0.043677	0.027368	1.595913	No	-0.00996	0.097318
Manufacturing	0.031593	0.025321	1.247685	No	-0.01804	0.081222
Recreation and Entertainment	-0.03405	0.029553	-1.15199	No	-0.09197	0.023879
Services	-0.05908	0.019872	-2.97275	Yes	-0.09802	-0.02013
Retail and Wholesale	-0.00026	0.014127	-0.01847	No	-0.02795	0.027427
Utilities and Construction	0.071924	0.023176	3.103446	Yes	0.0265	0.117348
Crime						
Aggravated Assault	-0.03572	0.027321	-1.30727	No	-0.08927	0.017833
Simple Assault	0.111016	0.026035	4.264132	Yes	0.059988	0.162045
Property Crime	0.035462	0.017703	2.003138	Yes	0.000764	0.070161
Violent Crime	-0.01596	0.024794	-0.64371	No	-0.06456	0.032637
Health Outcomes						
Opioids	-0.06968	0.03265	-2.13415	Yes	-0.13368	-0.00569
Alcohol	-0.22354	0.08995	-2.48515	Yes	-0.39984	-0.04724
Heart Disease	-0.05507	0.009795	-5.62257	Yes	-0.07427	-0.03588

Insurance						
Liability Amount	-0.01532	0.042605	-0.35958	No	-0.09883	0.068187
Indemnity Amount	1.156458	0.084906	13.62046	Yes	0.990043	1.322874
# Indemnity Policies	0.869058	0.056017	15.51426	Yes	0.759265	0.97885
Taxes and Revenue						
Total Revenue	0.004998	0.023048	0.216862	No	-0.04018	0.050171
Total Taxes	0.009473	0.025892	0.365845	No	-0.04128	0.060221

Table 17: Simulation of Proportional Impact of 2018 Drought on Otero County, Colorado

		Impact	**Standard error**	**t**	**Significant**	**Lower 95% CI**	**Upper 95% CI**
Agricultural Outcomes							
Corn Production		-0.03613	0.020376	-1.77325	No	-0.07607	0.003805
Hay Production		-0.08257	0.007544	-10.9457	Yes	-0.09736	-0.06779
Wheat Production		-0.14652	0.015873	-9.23085	Yes	-0.17764	-0.11541
Sorghum Production		-0.07654	0.023931	-3.19818	Yes	-0.12344	-0.02963
Corn Acres Harvested		0.057248	0.01852	3.091216	Yes	0.02095	0.093546
Hay Acres Harvested		-0.04107	0.006044	-6.79522	Yes	-0.05292	-0.02922
Wheat Acres Harvested		-0.06885	0.013454	-5.11736	Yes	-0.09522	-0.04248
Sorghum Acres Harvested		-0.00822	0.022373	-0.36748	No	-0.05207	0.035629
Employment							
Overall		-0.00949	0.003441	-2.75874	Yes	-0.01624	-0.00275
Ag Fish and Hunt		0.016167	0.010859	1.488846	No	-0.00512	0.037451

Education and Health	0.022629	0.010336	2.189449	Yes	0.002372	0.042887
Manufacturing	0.014177	0.009387	1.510326	No	-0.00422	0.032576
Recreation and Entertainment	-0.02529	0.012311	-2.05397	Yes	-0.04941	-0.00116
Services	-0.03015	0.007623	-3.95476	Yes	-0.04509	-0.01521
Retail and Wholesale	-0.01243	0.004203	-2.95694	Yes	-0.02067	-0.00419
Utilities and Construction	-0.02844	0.009379	-3.0321	Yes	-0.04682	-0.01005
Establishments						
Overall	-0.01894	0.003132	-6.04681	Yes	-0.02508	-0.0128
Ag Fish and Hunt	0.012334	0.007684	1.605149	No	-0.00273	0.027394
Education and Health	0.03639	0.007432	4.896409	Yes	0.021824	0.050957
Manufacturing	-0.00791	0.005833	-1.3556	No	-0.01934	0.003526
Recreation and Entertainment	-0.01675	0.007434	-2.25261	Yes	-0.03132	-0.00218
Services	-0.02573	0.004998	-5.14832	Yes	-0.03553	-0.01593
Retail and Wholesale	-0.0124	0.003283	-3.77624	Yes	-0.01883	-0.00596
Utilities and Construction	-0.0305	0.006345	-4.80731	Yes	-0.04294	-0.01806
Wage Bill						
Overall	-0.00744	0.004252	-1.74929	No	-0.01577	0.000896
Ag Fish and Hunt	0.006792	0.01157	0.58701	No	-0.01589	0.02947
Education and Health	0.018771	0.011993	1.565099	No	-0.00474	0.042278
Manufacturing	0.016897	0.010884	1.55244	No	-0.00444	0.038229
Recreation and Entertainment	-0.03343	0.014468	-2.31102	Yes	-0.06179	-0.00508
Services	-0.03386	0.008853	-3.82462	Yes	-0.05121	-0.01651

Retail and Wholesale	-0.01391	0.005552	-2.50501	Yes	-0.02479	-0.00303
Utilities and Construction	-0.03281	0.010911	-3.00667	Yes	-0.05419	-0.01142
Crime						
Aggravated Assault	0.008544	0.015301	0.558396	No	-0.02145	0.038533
Simple Assault	-0.01818	0.014104	-1.28937	No	-0.04583	0.009458
Property Crime	-0.00663	0.010144	-0.65341	No	-0.02651	0.013254
Violent Crime	0.00741	0.013685	0.541513	No	-0.01941	0.034232
Health Outcomes						
Opioids	0.035233	0.019724	1.786297	No	-0.00343	0.073892
Alcohol	-0.04484	0.06087	-0.73667	No	-0.16415	0.074464
Heart Disease	-0.0195	0.007619	-2.55869	Yes	-0.03443	-0.00456
Insurance						
Liability Amount	-0.04021	0.018384	-2.18709	Yes	-0.07624	-0.00417
Indemnity Amount	0.24725	0.037257	6.636312	Yes	0.174226	0.320274
# Indemnity Policies	0.172356	0.023863	7.222675	Yes	0.125584	0.219127
Taxes and Revenue						
Total Revenue	0.010326	0.011174	0.924095	No	-0.01158	0.032227
Total Taxes	0.015817	0.00961	1.645963	No	-0.00302	0.034653

Table 18: Proportional Impact of 2012 Drought on Employment and Establishments by Agricultural Sector in Otero County, CO

	Impact	Standard error	t	Significant	Lower 95% CI	Upper 95% CI
Employment						
Livestock	-0.02846	0.029502	-0.96454	No	-0.08628	0.029368
Crop Production	0.001777	0.032634	0.054466	No	-0.06219	0.06574
Agricultural Suppliers	-0.07637	0.037727	-2.02438	Yes	-0.15032	-0.00243
Establishments						
Livestock	0.032409	0.018519	1.750085	No	-0.00389	0.068706
Crop Production	0.065942	0.019796	3.330992	Yes	0.027141	0.104743
Agricultural Suppliers	-0.05275	0.022261	-2.36967	Yes	-0.09638	-0.00912
Wage Bill						
Livestock	-0.00886	0.030822	-0.28746	No	-0.06927	0.05155
Crop Production	0.004865	0.033586	0.144861	No	-0.06096	0.070694
Agricultural Suppliers	-0.07931	0.040764	-1.94571	No	-0.15921	0.000583

Table 19: Proportional Impact of 2018 Drought on Employment and Establishments by Agricultural Sector in Otero County, CO

	Impact	Standard error	t	Significant	Lower 95% CI	Upper 95% CI
Employment						
Livestock	0.02267	0.013455	1.684844	No	-0.0037	0.049042
Crop Production	-0.00525	0.015723	-0.33416	No	-0.03607	0.025562
Agricultural Suppliers	0.004429	0.016261	0.272355	No	-0.02744	0.0363
Establishments						
Livestock	0.017662	0.009574	1.844785	No	-0.0011	0.036426
Crop Production	0.022956	0.010708	2.143942	Yes	0.00197	0.043943
Agricultural Suppliers	0.007662	0.010786	0.710342	No	-0.01348	0.028802
Wage Bill						
Livestock	0.011889	0.013935	0.853145	No	-0.01542	0.039202
Crop Production	-0.0217	0.016128	-1.34519	No	-0.05331	0.009916
Agricultural Suppliers	-0.00694	0.017203	-0.40347	No	-0.04066	0.026777

Conclusions

This analysis evaluates the impact of drought on many sectors over an approximately forty-year period across the Western United States. Importantly, our approach distinguishes between the effect of prolonged drought conditions (as measured by PDSI) and the impact of contemporaneous variation in temperature and precipitation. Thus, simulated impacts reflect the combined effect associated with both prolonged drought conditions and short-term weather conditions within a given year.

Our primary results indicate that prolonged drought has a negative and statistically significant impact on corn, hay, and wheat production. Each additional month of extreme drought conditions (PDSI<-3) is associated with a decrease in total corn and wheat production of 3.2 and 3.7 percent, respectively. We also find that higher temperatures and precipitation have a positive and statistically significant impact on total agricultural production; however, these effects are diminishing with higher temperatures and become negative for conditions well above the mean.

The average analysis masks important heterogeneity. We find that drought conditions that occur during the growing season have a much larger negative impact on total production than those that occur during the non-growing season. For corn and wheat, the reduction in total production is largely driven by a decrease in harvested acres, whereas for hay the reduction in total production is primarily due to a decrease in yields per acre harvested. We also find evidence that the impact of drought on the agricultural economy is lower in counties with higher median incomes

Beyond agricultural production, we find that each additional month of extreme drought is associated with a reduction in total wages paid to employees in agriculture of approximately 0.5 percent, with total wages decreasing by roughly the same amount for those working in the agricultural supply sector. Extreme drought is also negatively associated with wages paid to employees in the recreation and entertainment sectors, but positively associated with total wages paid to those in the utility and construction sectors. Results are similar for total employment and number of establishments in each sector with the exception that livestock employment is negatively associated with extreme drought.

We also evaluate the impact of drought on public health and criminal activity. We find the average effect of an additional month of extreme drought is not statistically significant for opioid and alcohol related mortality, but we do find a negative association between extreme drought and heart disease mortality. We find suggestive evidence that moderate drought is associated with a decrease in simple assaults and property crime.

Finally, we explored the relationships between drought and insurance markets and total government revenue and tax. Unsurprisingly, indemnity amounts and insurance policy counts are positively correlated with extreme and moderate drought. We also find suggestive evidence that drought conditions are positively associated with total taxes and revenue.

The novelty of our study is that we use our overall results, combined with data on drought conditions in particular counties in particular years to simulate location and sector specific drought impacts. As an example, we simulate the impact of 2012 and 2018 drought conditions across a variety of economic sectors, public health, and criminal activity for Otero County, Colorado. This analysis can be performed for any county in our sample.

References

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Appendix 1: Regression Tables for Agricultural Impacts

Table A1: Drought Impacts on Crop Production

	(1) Corn	(2) Hay	(3) Wheat	(4) Sorghum
PDSI <- 3	-0.0323***	-0.0222***	-0.0364***	-0.0273***
	(0.00402)	(0.00194)	(0.00370)	(0.00589)
PDSI between -3 and -1	-0.00847***	-0.00793***	-0.0191***	-0.0168***
	(0.00252)	(0.00115)	(0.00203)	(0.00314)
PDSI between 1 and 3	-0.0106***	-0.000539	-0.00302	0.000438
	(0.00238)	(0.00107)	(0.00224)	(0.00288)
PDSI > 3	-0.0179***	-0.00480***	-0.00985***	0.0151***
	(0.00334)	(0.00137)	(0.00246)	(0.00366)
Annual average temperature	0.268***	0.0710***	0.234***	0.274***
	(0.0448)	(0.0210)	(0.0303)	(0.0606)
Annual average temperature	-0.00894***	-0.00273***	-0.00641***	-0.00536***
squared	(0.00124)	(0.000596)	(0.000857)	(0.00145)
Precipitation	0.000679***	0.000551***	0.000175*	0.00123***
	(0.000127)	(4.62e-05)	(0.000103)	(0.000183)
Precipitation squared	-3.62e-07***	-1.31e-07***	-2.29e-07***	-5.93e-07***
	(6.73e-08)	(1.61e-08)	(4.76e-08)	(9.54e-08)
Constant	11.10***	9.941***	11.41***	9.015***
	(0.432)	(0.195)	(0.297)	(0.711)

County fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	14,488	16,671	18,697	12,908
R-squared	0.333	0.124	0.176	0.223
Number of fips	618	773	808	544

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

Table A2: Drought Impacts on Yield Per Acre

	(1)	(2)	(3)	(4)
	Corn	Hay	Wheat	Sorghum
PDSI <- 3	-0.0157***	-0.0187***	-0.0164***	-0.0250***
	(0.00154)	(0.00111)	(0.00166)	(0.00202)
PDSI between -3	-0.000835	-0.00512***	-0.00832***	-0.00723***
and -1	(0.000906)	(0.000653)	(0.000975)	(0.000991)
PDSI between 1	-0.00430***	-5.10e-05	0.00115	-0.00369***
and 3	(0.000821)	(0.000603)	(0.000786)	(0.000890)
PDSI > 3	-0.00978***	-0.00375***	-0.00598***	-0.00897***
	(0.00101)	(0.000700)	(0.000911)	(0.00107)
Annual average	0.140***	0.112***	0.0551***	0.152***
temperature	(0.0184)	(0.0123)	(0.0132)	(0.0225)
Temperature	-0.00559***	-0.00355***	-0.00170***	-0.00536***
squared	(0.000511)	(0.000367)	(0.000362)	(0.000574)
Precipitation	0.000173***	0.000371***	-5.43e-05	0.000778***
	(5.67e-05)	(2.47e-05)	(5.86e-05)	(8.22e-05)
Precipitation	-4.71e-08*	-8.39e-08***	-1.00e-07***	-3.69e-07***
squared	(2.84e-08)	(6.54e-09)	(3.08e-08)	(4.44e-08)
Constant	3.779***	-0.172	3.198***	2.677***
	(0.177)	(0.107)	(0.129)	(0.232)
County fixed effects	yes	yes	yes	yes

Year fixed effects	yes	yes	yes	yes
Observations	14,488	16,671	18,697	12,908
R-squared	0.319	0.191	0.161	0.313
Number of fips	618	773	808	544

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Table A3: Drought Impacts on Harvested Acres

	(1)	(2)	(3)	(4)
	Corn	Hay	Wheat	Sorghum
PDSI <- 3	-0.0166***	-0.00347**	-0.0201***	-0.00230
	(0.00367)	(0.00165)	(0.00294)	(0.00517)
PDSI between	-0.00764***	-0.00281***	-0.0108***	-0.00956***
-3 and -1	(0.00244)	(0.000917)	(0.00171)	(0.00303)
PDSI between	-0.00633***	-0.000488	-0.00418**	0.00412
1 and 3	(0.00232)	(0.000881)	(0.00198)	(0.00267)
PDSI > 3	-0.00812**	-0.00106	-0.00387*	0.0241***
	(0.00317)	(0.00109)	(0.00213)	(0.00339)
Annual average	0.128***	-0.0412***	0.179***	0.122**
temperature	(0.0408)	(0.0151)	(0.0243)	(0.0580)
Temperature	-0.00335***	0.000818*	-0.00471***	-5.92e-06
squared	(0.00108)	(0.000421)	(0.000701)	(0.00141)
Precipitation	0.000507***	0.000180***	0.000229***	0.000448***
	(0.000120)	(3.63e-05)	(8.17e-05)	(0.000155)
Precipitation	-3.15e-07***	-4.70e-08***	-1.29e-07***	-2.24e-07***
squared	(6.12e-08)	(1.27e-08)	(3.61e-08)	(7.83e-08)
Constant	7.317***	10.11***	8.216***	6.338***
	(0.424)	(0.144)	(0.242)	(0.672)
	-0.0166***	-0.00347**	-0.0201***	-0.00230
County fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes

Observations	14,488	16,671	18,697	12,908
R-squared	0.219	0.045	0.215	0.228
Number of fips	618	773	808	544

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Table A4: Drought Impacts on Crop Production-Groundwater Versus Non-Groundwater Dependent Counties

	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	Corn		Wheat		Hay		Sorghum	
	No GW	GW	No GW	GW	No GW	GW	No GW	GW
PDSI <- 3	-0.0360***	-0.0310***	-0.0298***	-0.0126***	-0.0392***	-0.0315***	-0.0346***	-0.0207***
	(0.00626)	(0.00525)	(0.00243)	(0.00312)	(0.00494)	(0.00590)	(0.0119)	(0.00697)
PDSI between -3 and -1	-0.0116***	-0.00639**	-0.00933***	-0.00556***	-0.0163***	-0.0175***	-0.0152**	-0.0165***
	(0.00425)	(0.00313)	(0.00156)	(0.00170)	(0.00324)	(0.00259)	(0.00601)	(0.00370)
PDSI between 1 and 3	-0.0157***	-0.00602**	-0.00241*	0.00257	-0.0135***	0.00542*	-0.00788	0.00233
	(0.00400)	(0.00302)	(0.00141)	(0.00170)	(0.00354)	(0.00276)	(0.00563)	(0.00344)
PDSI > 3	-0.0199***	-0.0179***	-0.00603***	-0.00275	-0.0242***	0.000656	0.00458	0.0178***
	(0.00525)	(0.00425)	(0.00169)	(0.00243)	(0.00364)	(0.00313)	(0.00603)	(0.00471)
Annual average temperature	0.117	0.413***	0.00455	0.207***	0.153***	0.391***	-0.0304	0.318***
	(0.0745)	(0.0534)	(0.0234)	(0.0448)	(0.0386)	(0.0581)	(0.164)	(0.0675)
Annual average temperature squared	-0.00568***	-0.0119***	-0.00128*	-0.00597***	-0.00407***	-0.0104***	-0.00150	-0.00562***
	(0.00205)	(0.00148)	(0.000680)	(0.00123)	(0.00121)	(0.00151)	(0.00359)	(0.00166)

Precipitation	0.00109***	0.000553***	0.000507***	0.000655***	0.000834***	-0.000339***	0.000569	0.00171***
	(0.000287)	(0.000140)	(5.71e-05)	(6.89e-05)	(0.000180)	(0.000122)	(0.000387)	(0.000217)
Precipitation squared	-5.20e-07***	-3.12e-07***	-1.20e-07***	-1.62e-07***	-4.20e-07***	-7.64e-08	-2.68e-07	-9.00e-07***
	(1.40e-07)	(7.82e-08)	(1.82e-08)	(2.31e-08)	(8.19e-08)	(5.40e-08)	(1.75e-07)	(1.18e-07)
Constant	11.40***	10.10***	10.68***	8.458***	11.54***	10.33***	13.79***	8.140***
	(0.718)	(0.527)	(0.218)	(0.420)	(0.356)	(0.589)	(2.034)	(0.773)
County fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Observations	5,206	9,282	8,505	8,166	8,523	10,174	3,243	9,665
R-squared	0.327	0.351	0.148	0.129	0.167	0.225	0.304	0.218
Number of fips	263	355	360	413	386	422	168	376

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Table A5: Drought Impacts on Yield Per Acre-Groundwater Versus Non-Groundwater Dependent Counties

	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	Corn		Wheat		Hay		Sorghum	
	No GW	GW	No GW	GW	No GW	GW	No GW	GW
PDSI <- 3	-0.0108***	-0.0194***	-0.0161***	-0.0216***	-0.0168***	-0.0144***	-0.0206***	-0.0263***
	(0.00232)	(0.00198)	(0.00152)	(0.00157)	(0.00225)	(0.00237)	(0.00401)	(0.00227)
PDSI between -3 and -1	-0.000729	-0.000923	-0.00452***	-0.00517***	-0.00732***	-0.00687***	-0.00295	-0.00820***
	(0.00166)	(0.00108)	(0.000895)	(0.000991)	(0.00151)	(0.00126)	(0.00217)	(0.00113)
PDSI between 1 and 3	-0.00404***	-0.00389***	-8.93e-05	0.000243	-0.000988	0.00281***	-0.00556***	-0.00287***
	(0.00144)	(0.00101)	(0.000821)	(0.000864)	(0.00122)	(0.00102)	(0.00201)	(0.000993)
PDSI > 3	-0.0110***	-0.00892***	-0.00313***	-0.00435***	-0.00809***	-0.00424***	-0.0101***	-0.00764***
	(0.00154)	(0.00132)	(0.000939)	(0.00106)	(0.00134)	(0.00120)	(0.00215)	(0.00130)
Annual average temperature	0.104***	0.155***	0.103***	0.172***	-0.0305*	0.198***	0.00170	0.187***
	(0.0252)	(0.0247)	(0.0142)	(0.0268)	(0.0162)	(0.0260)	(0.0574)	(0.0239)

Annual average temperature squared	-0.00487***	-0.00595***	-0.00357***	-0.00488***	0.000888*	-0.00554***	-0.00276**	-0.00584***
	(0.000694)	(0.000692)	(0.000450)	(0.000743)	(0.000480)	(0.000662)	(0.00134)	(0.000633)
Precipitation	0.000505***	1.52e-05	0.000356***	0.000384***	0.000296***	-0.000360***	0.000549***	0.00104***
	(0.000109)	(5.98e-05)	(3.10e-05)	(3.94e-05)	(0.000104)	(5.90e-05)	(0.000179)	(0.000100)
Precipitation squared	-1.84e-07***	1.52e-08	-8.11e-08***	-8.36e-08***	-2.20e-07***	1.65e-08	-2.27e-07***	-5.64e-07***
	(5.03e-08)	(3.00e-08)	(7.83e-09)	(1.08e-08)	(5.06e-08)	(3.22e-08)	(8.15e-08)	(5.77e-08)
Constant	3.926***	3.760***	-0.103	-0.723***	3.755***	2.011***	4.698***	2.104***
	(0.244)	(0.240)	(0.116)	(0.245)	(0.155)	(0.266)	(0.660)	(0.236)
County fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Observations	5,206	9,282	8,505	8,166	8,523	10,174	3,243	9,665
R-squared	0.354	0.315	0.194	0.209	0.139	0.237	0.356	0.321
Number of Counties	263	355	360	413	386	422	168	376

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Table A6: Drought Impacts on Harvested Acres-Groundwater Versus Non-Groundwater Dependent Counties

	(1) Corn No GW	(2) GW	(3) Wheat No GW	(4) GW	(1) Hay No GW	(2) GW	(3) Sorghum No GW	(4) GW
PDSI <- 3	-0.0252***	-0.0116**	-0.0137***	0.00902***	-0.0224***	-0.0171***	-0.0140	0.00554
	(0.00553)	(0.00489)	(0.00192)	(0.00269)	(0.00397)	(0.00472)	(0.0101)	(0.00628)
PDSI between -3 and -1	-0.0109***	-0.00547*	-0.00481***	-0.000386	-0.00902***	-0.0106***	-0.0122**	-0.00825**
	(0.00394)	(0.00315)	(0.00121)	(0.00139)	(0.00278)	(0.00218)	(0.00547)	(0.00360)
PDSI between 1 and 3	-0.0117***	-0.00213	-0.00232**	0.00233	-0.0125***	0.00262	-0.00232	0.00520
	(0.00374)	(0.00297)	(0.00112)	(0.00145)	(0.00318)	(0.00250)	(0.00498)	(0.00326)
PDSI > 3	-0.00896*	-0.00894**	-0.00289**	0.00159	-0.0162***	0.00490*	0.0146***	0.0254***
	(0.00486)	(0.00418)	(0.00129)	(0.00201)	(0.00314)	(0.00283)	(0.00557)	(0.00439)
Annual average temperature	0.0125	0.258***	-0.0982***	0.0351	0.183***	0.193***	-0.0321	0.131**
	(0.0675)	(0.0495)	(0.0174)	(0.0306)	(0.0315)	(0.0455)	(0.145)	(0.0665)
Annual average temperature squared	-0.000816	-0.00591***	0.00229***	-0.00109	-0.00496***	-0.00486***	0.00126	0.000222

	(0.00180)	(0.00132)	(0.000494)	(0.000840)	(0.000984)	(0.00123)	(0.00327)	(0.00166)
Precipitation	0.000588**	0.000538***	0.000151***	0.000272***	0.000538***	2.05e-05	1.98e-05	0.000665***
	(0.000266)	(0.000131)	(4.31e-05)	(5.90e-05)	(0.000137)	(0.000105)	(0.000300)	(0.000197)
Precipitation squared	-3.37e-07***	-3.27e-07***	-3.85e-08***	-7.87e-08***	-1.99e-07***	-9.29e-08**	-4.07e-08	-3.36e-07***
	(1.27e-07)	(7.21e-08)	(1.37e-08)	(2.09e-08)	(5.98e-08)	(4.48e-08)	(1.39e-07)	(1.08e-07)
Constant	7.472***	6.342***	10.79***	9.182***	7.787***	8.316***	9.090***	6.035***
	(0.685)	(0.526)	(0.163)	(0.293)	(0.302)	(0.453)	(1.724)	(0.756)
County fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Observations	5,206	9,282	8,505	8,166	8,523	10,174	3,243	9,665
R-squared	0.222	0.234	0.065	0.062	0.227	0.228	0.351	0.209
Number of Counties	263	355	360	413	386	422	168	376

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin.

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

Table A7: Drought Impacts on Crop Production by Growing Season and Non-Growing Season

	(5)	(6)	(7)	(8)
	Corn	Hay	Wheat	Sorghum
Growing season PDSI <- 3	-0.0468***	-0.0435***	-0.0620***	-0.0734***
	(0.00745)	(0.00379)	(0.00689)	(0.0102)
Growing season PDSI between -3 and -1	-0.00599	-0.00972***	-0.0247***	-0.0291***
	(0.00434)	(0.00184)	(0.00334)	(0.00548)
Growing season PDSI between 1 and 3	-0.0309***	0.000145	0.0125***	-0.00623
	(0.00425)	(0.00178)	(0.00334)	(0.00463)
Growing season PDSI > 3	-0.0563***	-0.00182	0.0275***	0.0135*
	(0.00707)	(0.00301)	(0.00557)	(0.00818)
Non-growing season PDSI <- 3	-0.0100	0.00705	-0.00192	0.0315*
	(0.0110)	(0.00510)	(0.00950)	(0.0170)
Non-growing season PDSI between -3 and -1	-0.0110**	-0.00514**	-0.0122***	-0.00310
	(0.00502)	(0.00224)	(0.00424)	(0.00673)
Non-growing season PDSI between 1 and 3	0.0145**	-0.00159	-0.0236***	0.00771
	(0.00584)	(0.00233)	(0.00466)	(0.00705)
Non-growing season PDSI > 3	0.0255**	-0.00855**	-0.0548***	0.0162
	(0.0100)	(0.00390)	(0.00749)	(0.0106)
Annual average temperature	0.303***	0.0685***	0.205***	0.264***
	(0.0454)	(0.0212)	(0.0297)	(0.0616)
Annual average temperature squared	-0.00974***	-0.00270***	-0.00580***	-0.00503***
	(0.00124)	(0.000597)	(0.000835)	(0.00147)
Precipitation	0.000697***	0.000552***	0.000140	0.00125***

	(0.000127)	(4.60e-05)	(0.000102)	(0.000182)
Precipitation squared	-3.70e-07***	-1.29e-07***	-2.10e-07***	-5.99e-07***
	(6.72e-08)	(1.59e-08)	(4.71e-08)	(9.51e-08)
Constant	10.73***	9.962***	11.73***	9.049***
	(0.442)	(0.198)	(0.296)	(0.725)
County fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	14,488	16,671	18,697	12,908
R-squared	0.336	0.128	0.181	0.225
Number of Counties	618	773	808	544

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin. Growing season defined as April to September.

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

Table A8: Drought Impacts on Yield Per Acre by Growing Season and Non-Growing Season

	(5)	(6)	(7)	(8)
	Corn	Hay	Wheat	Sorghum
Growing season PDSI <- 3	-0.0282***	-0.0234***	-0.0346***	-0.0300***
	(0.00362)	(0.00239)	(0.00292)	(0.00377)
Growing season PDSI between -3 and -1	-0.00938***	-0.00521***	-0.0141***	-0.00871***
	(0.00165)	(0.00111)	(0.00144)	(0.00193)
Growing season PDSI between 1 and 3	-0.00379**	-0.000438	0.00783***	-0.00670***
	(0.00159)	(0.00104)	(0.00136)	(0.00171)
Growing season PDSI > 3	-0.00680**	-0.00507***	0.0130***	-0.0137***
	(0.00282)	(0.00175)	(0.00232)	(0.00271)
Non-growing season PDSI <- 3	-0.00133	-0.0121***	0.00779**	-0.0187***
	(0.00416)	(0.00289)	(0.00371)	(0.00514)
Non-growing season PDSI between -3 and -1	0.00908***	-0.00495***	-0.00134	-0.00555**
	(0.00192)	(0.00128)	(0.00179)	(0.00237)
Non-growing season PDSI between 1 and 3	-0.00547***	0.000405	-0.00801***	-1.44e-05
	(0.00198)	(0.00128)	(0.00158)	(0.00195)
Non-growing season PDSI > 3	-0.0129***	-0.00227	-0.0290***	-0.00344
	(0.00320)	(0.00213)	(0.00266)	(0.00319)
Annual average temperature	0.135***	0.113***	0.0397***	0.156***
	(0.0180)	(0.0123)	(0.0127)	(0.0229)
Annual average temperature squared	-0.00545***	-0.00356***	-0.00137***	-0.00542***
	(0.000502)	(0.000367)	(0.000348)	(0.000583)

Precipitation	0.000162***	0.000372***	-7.54e-05	0.000778***
	(5.65e-05)	(2.47e-05)	(5.82e-05)	(8.23e-05)
Precipitation squared	-4.35e-08	-8.38e-08***	-8.94e-08***	-3.70e-07***
	(2.83e-08)	(6.55e-09)	(3.04e-08)	(4.44e-08)
Constant	3.832***	-0.181*	3.367***	2.627***
	(0.175)	(0.108)	(0.126)	(0.237)
County fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	14,488	16,671	18,697	12,908
R-squared	0.322	0.192	0.170	0.314
Number of Counties	618	773	808	544

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin. Growing season defined as April to September.

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

Table A9: Drought Impacts on Harvested Acres by Growing Season and Non-Growing Season

	(5) Corn	(6) Hay	(7) Wheat	(8) Sorghum
Growing season PDSI <- 3	-0.0185***	-0.0200***	-0.0274***	-0.0434***
	(0.00679)	(0.00287)	(0.00572)	(0.00944)
Growing season PDSI between -3 and -1	0.00339	-0.00451***	-0.0106***	-0.0204***
	(0.00429)	(0.00150)	(0.00299)	(0.00502)
Growing season PDSI between 1 and 3	-0.0271***	0.000583	0.00464	0.000470
	(0.00392)	(0.00158)	(0.00296)	(0.00433)
Growing season PDSI > 3	-0.0495***	0.00325	0.0145***	0.0272***
	(0.00649)	(0.00257)	(0.00471)	(0.00779)
Non-growing season PDSI <- 3	-0.00870	0.0192***	-0.00971	0.0502***
	(0.0100)	(0.00414)	(0.00827)	(0.0151)
Non-growing season PDSI between -3 and -1	-0.0201***	-0.000189	-0.0109***	0.00244
	(0.00495)	(0.00195)	(0.00376)	(0.00620)
Non-growing season PDSI between 1 and 3	0.0199***	-0.00199	-0.0156***	0.00772
	(0.00560)	(0.00204)	(0.00429)	(0.00678)
Non-growing season PDSI > 3	0.0383***	-0.00628**	-0.0259***	0.0196**
	(0.00932)	(0.00314)	(0.00663)	(0.00991)
Annual average temperature	0.168***	-0.0442***	0.165***	0.108*
	(0.0421)	(0.0154)	(0.0243)	(0.0585)
Annual average temperature squared	-0.00429***	0.000861**	-0.00443***	0.000396
	(0.00110)	(0.000423)	(0.000693)	(0.00142)

Precipitation	0.000535***	0.000180***	0.000215***	0.000468***
	(0.000120)	(3.62e-05)	(8.16e-05)	(0.000154)
Precipitation squared	-3.27e-07***	-4.56e-08***	-1.20e-07***	-2.29e-07***
	(6.15e-08)	(1.26e-08)	(3.60e-08)	(7.82e-08)
Constant	6.895***	10.14***	8.363***	6.423***
	(0.439)	(0.148)	(0.244)	(0.677)
County fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Observations	14,488	16,671	18,697	12,908
R-squared	0.225	0.048	0.216	0.229
Number of Counties	618	773	808	544

Standard errors in parentheses clustered at the county level. Impacts are relative to a month with PDSI between -1 and 1. All dependent variables are logged. PDSI variables are number of months with PDSI in indicated bin. Growing season defined as April to September.

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

Table A10: Agricultural Results with HUC Level PDSI Counts

VARIABLES	(1) Corn	(2) Hay	(3) Wheat	(4) Sorghum
PDSI<-3	-0.0321***	-0.0211***	-0.0382***	-0.0296***
	(0.00450)	(0.00225)	(0.00438)	(0.00690)
PDSI -3 to-1	-0.00628**	-0.00581***	-0.0174***	-0.0155***
	(0.00286)	(0.00133)	(0.00228)	(0.00350)
PDSI 1 to 3	-0.00880***	6.66e-06	-0.00252	0.00215
	(0.00282)	(0.00120)	(0.00253)	(0.00327)
PDSI >3	-0.0164***	-0.00272*	-0.00905***	0.0155***
	(0.00384)	(0.00151)	(0.00286)	(0.00404)
HUC Level PDSI<--3	-5.95e-05	-0.000394	0.00129*	0.000373
	(0.000959)	(0.000495)	(0.000736)	(0.00113)
HUC Level PDSI -3 to-1	-0.00144*	-0.000938***	-0.00125**	-0.00161**
	(0.000808)	(0.000321)	(0.000539)	(0.000720)
HUC Level PDSI 1 to 3	-0.00122	4.98e-05	-0.000847	-0.00159**
	(0.000914)	(0.000333)	(0.000666)	(0.000703)
HUC Level PDSI >3	-0.000754	-0.000779**	-0.000693	-0.000291
	(0.000855)	(0.000346)	(0.000576)	(0.000658)
Annual average temperature	0.283***	0.0925***	0.248***	0.268***
	(0.0459)	(0.0209)	(0.0315)	(0.0630)
Annual average temperature squared	-0.00938***	-0.00337***	-0.00683***	-0.00513***

	(0.00128)	(0.000578)	(0.000888)	(0.00151)
Precipitation	0.000709***	0.000537***	0.000194*	0.00117***
	(0.000141)	(4.89e-05)	(0.000107)	(0.000188)
Precipitation squared	-3.84e-07***	-1.29e-07***	-2.44e-07***	-5.64e-07***
	(7.59e-08)	(1.74e-08)	(5.03e-08)	(9.78e-08)
Constant	10.99***	9.773***	11.33***	9.071***
	(0.440)	(0.204)	(0.313)	(0.737)
Observations	13,537	15,027	17,055	12,087
R-squared	0.341	0.132	0.179	0.225
Number of fips	563	700	732	507

Robust standard errors in parentheses

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

Table A11: Agricultural Results with HUC Level PDSI Counts without County Counts

VARIABLES	(1) Corn	(2) Hay	(3) Wheat	(4) Sorghum
HUC Level PDSI<--3	-0.00253***	-0.00235***	-0.00214**	-0.000708
	(0.000876)	(0.000635)	(0.000862)	(0.000999)
HUC Level PDSI -3 to-1	-0.00202***	-0.00150***	-0.00283***	-0.00228***
	(0.000749)	(0.000334)	(0.000570)	(0.000691)
HUC Level PDSI 1 to 3	-0.00224***	-0.000253	-0.00147**	-0.00166**
	(0.000837)	(0.000334)	(0.000649)	(0.000656)
HUC Level PDSI >3	-0.00254***	-0.00150***	-0.00236***	0.000688
	(0.000783)	(0.000346)	(0.000559)	(0.000671)
Annual average temperature	0.295***	0.0803***	0.229***	0.259***
	(0.0474)	(0.0210)	(0.0315)	(0.0631)
Annual average temperature squared	-0.00996***	-0.00345***	-0.00718***	-0.00586***
	(0.00132)	(0.000588)	(0.000885)	(0.00152)
Precipitation	0.000822***	0.000669***	0.000478***	0.00153***
	(0.000139)	(5.29e-05)	(0.000109)	(0.000192)
Precipitation squared	-4.37e-07***	-1.52e-07***	-3.21e-07***	-6.28e-07***
	(7.47e-08)	(1.94e-08)	(5.33e-08)	(9.84e-08)
Constant	10.92***	9.944***	11.67***	9.394***
	(0.448)	(0.203)	(0.312)	(0.735)
Observations	13,537	15,027	17,055	12,087

R-squared	0.336	0.122	0.170	0.220
Number of fips	563	700	732	507

Robust standard errors in parentheses

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