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Drought and Cattle: Implications for Ranchers

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Abstract

Drought has become more intense and frequent in many areas of the United States in recent years. Despite growing concerns about drought's effects on the agricultural sector, few studies have quantified its effects on the cattle industry. In this paper, we estimate the effects of drought on cattle herd management, hay production, hay prices, and farm income in the United States from 2000 to 2022. We find that drought reduces hay production and leads to higher hay prices. We also find that drought contributes to herd liquidation: as drought intensity increases, average herd size declines. These declines in average herd size lead revenues to temporarily increase, perhaps due to farmers selling larger quantities of market and breeding stock. Finally, we find that drought is correlated with lower farm incomes. Overall, our results suggest drought has a temporary positive effect on rancher revenues, but a negative effect on earnings.

Keywords: Drought, Climate Risk, Cattle, Ranchland, Farm Income
JEL Classification Codes: Q54, Q12, Q25

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*The views expressed here are those of the authors and are not attributable to the Federal Reserve Bank of Kansas City or the Federal Reserve System. Rodziewicz: Federal Reserve Bank of Kansas City, Denver Branch; Dice: Federal Reserve Bank of Kansas City, Center for the Advancement of Data and Research in Economics (CADRE); Cowley: Federal Reserve Bank of Kansas City, Oklahoma City Branch.

1 Introduction

Drought is a persistent and substantial threat to livestock and the functioning of agronomic systems (USGCRP 2018). Over the last couple of decades, large drought events have cost the United States a little over $190 billion in losses over the last couple decades and accounted for nearly 10 percent of large climate-related natural disaster losses (NOAA 2022). This threat has only intensified. Since mid-summer 2020, at least 50 percent of the land area in the continental United States has been in some level of drought. And by fall 2022, drought had intensified and spread to more than 85 percent of U.S. land area (USDM 2022). Warmer and dryer conditions were especially severe across the Plains and western United States, areas where a majority of the country's cattle are produced.

Cattle producers may be especially vulnerable to drought because it has the potential to put upward pressure on costs (e.g., feed and other operational costs) and downward pressure on farm incomes. In late 2022, for example, dry pastures contributed to tighter hay supplies, higher feed expenses, earlier weaning and sales, and larger herd liquidations for ranchers than in previous years (Scott & Kreitman 2023). Although drought can have a substantial effect on cattle production, few studies have quantified the historical effects of drought on the U.S. cattle industry. Most previous literature on the effects of drought in the agricultural sector focuses on crops. For example, Kuwayama et al. (2019), estimate the effects of drought on crop yields and farm income using the U.S. Drought Monitor (USDM) (USDM 2022). Other research identifies how drought can influence yields across types of crop production and highlights that agriculture productivity may decline over-time due to a changing climate (Challinor et al. 2014; Kupal & Irmak 2018; Schlenker 2020).

One common result from previous studies on the effects of drought in the crop sector is that although drought has a significant effect on crop yields, it does not significantly effect farm income. For commodity crop producers crop insurance is widely available. Although farmers can still face losses, which can differ by type of production (Rodziewicz & Dice 2020), crop insurance typically offsets any major adverse effects of lower production and revenues associated with drought (FCA 2017; CRS 2018).

However, this result is not likely to hold for cattle producers. In the case of ranchers, livestock insurance is relatively new, not as widespread in use, limited in scope, and only covers certain hazards (USDAc 2022). Thus, farm finances for cattle operations may be more susceptible to drought than finances for other types of production (Molieleng et al. 2021). In addition, cattle ranchers may use different adaptation strategies than crop producers in the midst of drought, such as moving herds or selling breeding cows or replacement heifers, all of which increase the cost of production (Skidmore 2022). Thus in this study, we seek to determine the effects of drought on herd management, hay production, hay prices, and farm income for cattle operations in the United States.

We use a panel regression framework with fixed effects to examine the relationship between drought conditions and agricultural outcomes for ranchers at the county-level. Our empirical strategy follows a similar approach to Kuwayama et al. (2019) and Rodziewicz and Dice (2020). In our analysis, we first identify which cattle production areas are exposed to drought. We combine data from the USDM with land use data from the U.S. Department of Agriculture's (USDA) CropScape Data Layer to measure weekly, crop-specific exposure to drought which we then average across the year (USDAa 2022). We specifically target pastureland, hay, and alfalfa because these land uses account for most of the forage produced for beef cow-calf operations. After matching drought exposure to areas of cattle production at the county-level, our empirical model estimates the effects of rising drought intensity on cattle herd sizes, hay production, hay prices, and farm economics (i.e. revenues and income). We find that a one-unit increase in average annual drought intensity is associated with a 1 percent decrease in average herd size, a 1 percent increase in revenues, and a 4 percent decrease in farm income. We find that a one-unit increase in annual average drought intensity is also associated with a 12 percent decline in hay production and 5 percent increase in hay prices. Additionally, we find that these effects are more pronounced in areas where drought is more severe.

2 Background

The production of beef begins on cow-calf operations (see Figure 1). Cattle ranchers breed cows each year, and calves are born in the spring or fall after a gestation period of about nine months. Calves are typically weaned after four to six months and weigh about 500 pounds. Each year, producers decide which heifer (female) calves to keep and which older cows to cull. Male calves are castrated and moved to stocker or backgrounding operations, along with any heifer calves that are not retained as replacement cows. Stocker calves gain about 300 pounds eating grass, winter wheat, or feed before moving into a feedlot to be finished for processing.

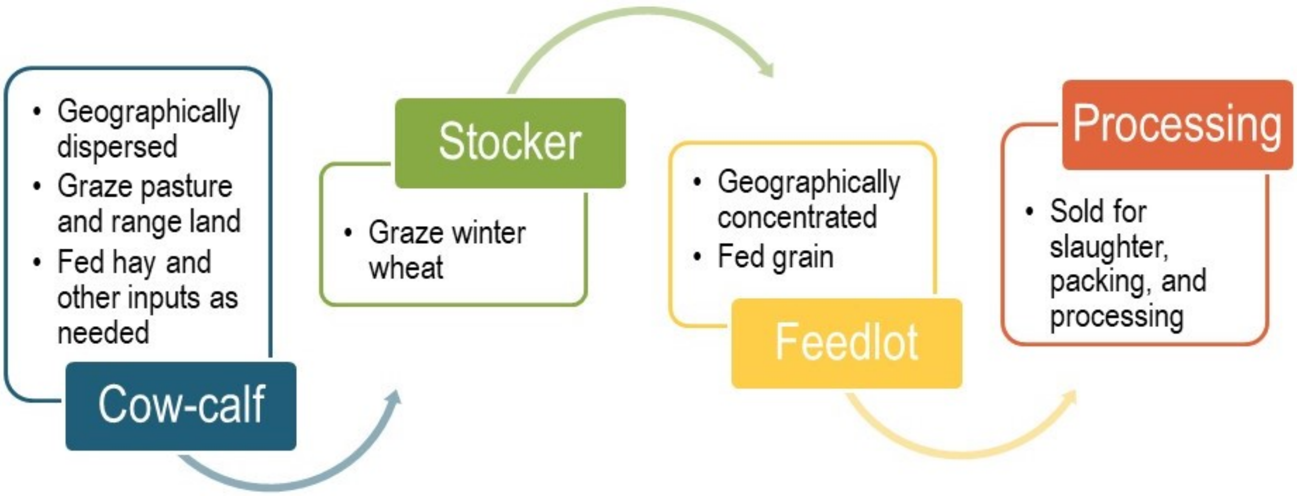

Figure 1: Beef Cattle Production Cycle

Cattle ranchers face unique risks associated with drought. Extreme heat associated with drought can lead to heat stress for cattle, reduced water and forage availability, and even animal death (Reidmiller et al. 2018). Cow-calf operations also are more geographically dispersed than other segments of the beef supply chain and utilize a significant amount of land. In fact, according to USDA (2017), about 654 million acres are used for livestock grazing in the United States. In

2017, grassland pasture and range land were the most common land uses, representing almost 35 percent of the total land area in the continental United States. Because cow-calf operations typically cover a larger area than other types of livestock operations, such as confined feedlots, they could be more likely to experience drought on some or all of their land area.

Grass (from pasture and range land) and hay are the primary feed inputs for cows and calves. Grass, alfalfa hay, and non-alflafa hay are deep-rooting perennial crops and are relatively more drought tolerant than other crops (Bauder 1978). However, drought can still have an effect on the condition and level of forage production. According to USDM (2022), damage to pasture and crops can begin in the earliest stages of moderate drought and worsen as drought becomes more widespread and severe. For most non-alfalfa hay and pasture grass, the risks of drought may be elevated because these land uses typically are not irrigated. However, alfalfa is more commonly irrigated. Alfalfa has higher water use requirements overall, due partially to its long growing season and dense mass of vegetation (Bauder 1978). Moreover, a majority of the alfalfa grown and harvested in the United States is located in more arid areas of the west and southwest (USDA 2018).

Historically, drought has had a notable effect on hay production. When more than 15 percent of land used to grow hay is experiencing the highest levels (D2-D4) of drought, hay production has declined in all years but one (see Figure 2, Panel A). Adverse growing conditions and reduced hay production associated with drought contribute to reduced feed availability and higher feed costs for producers. Figure 2, Panel B shows that from 2000 to 2020, hay prices were substantially higher in years with lower hay production. In that 20-year period, yearly hay production ranged from a low of about 117 million tons in 2012 (when 30 percent of hay land was in the highest level of drought) to a peak of 158 million tons in 2004 (when less than 10 percent of hay land was in the highest level of drought). Although hay production was 35 percent lower in 2012 than 2004, hay prices were more than twice as high. More recently, the United States has again been experiencing exceptional and persistent drought. Hay production in 2022 was slightly lower than in 2012. In some areas of the country, hay prices increased by as much as 56 percent from the previous year, and feed grain costs were at least 15 percent above 2021 levels (BLS 2023). [1]

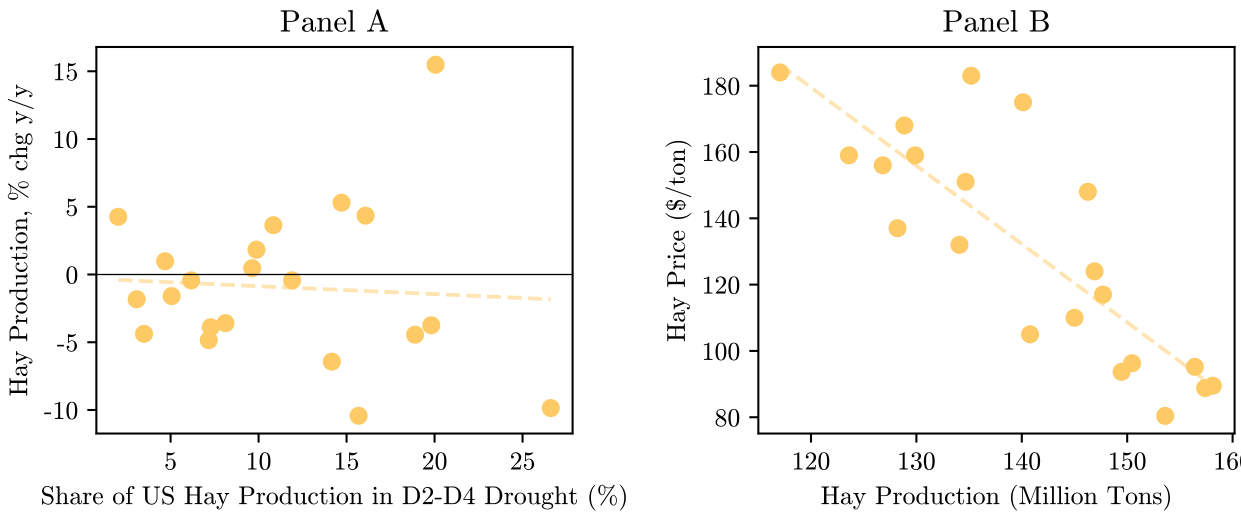

Figure 2: Drought, Hay Production, and Hay Prices

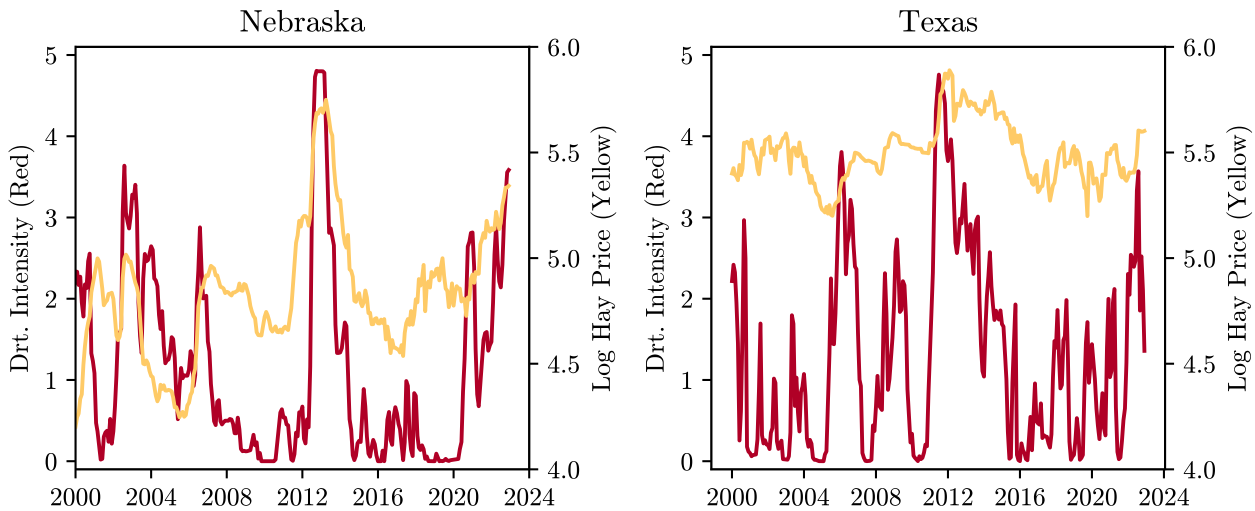

Figure 3: Drought and Hay Prices

Furthermore, at the state level, there is a notable relationship between drought intensity and hay prices that varies somewhat by location. Figure 3 shows a consistent relationship between drought severity (red) and hay prices (yellow) in Nebraska, with noticeable upward movements

[1]Although 20 percnet of U.S. hay ground was in severe to exceptional drought in 2013, hay production increased 16 percent. However, the country was coming out of one of the worst droughts on record, and hay production had declined by an average annual rate of 7 percent in the three preceding years. Therefore, 2013 could be an exception because the increase in hay production was from very low levels in 2012.

in hay prices as drought increases. For Texas, instances of more intense drought also seem to be followed by increases in hay prices, but the movement in hay prices are less pronounced. However, hay prices in Texas tend to remain at more elevated levels than hay prices in Nebraska, on average. More elevated hay prices in Texas could be due to more frequent and severe instances of drought. Also, the severity of drought in Texas appears to be more volatile than in Nebraska. Given how localized hay markets are and the differences across states, it is important to analyze the relationship between drought and hay at local or regional levels.

On the revenue side, because cattle are sold by weight, early weaning and liquidation could reduce profitability if producers are forced to sell cattle at lighter weights. However, if cattle sales are substantial enough (even at lower weights) ranchers may see a temporary boost in revenues. Still, if drought conditions are so severe that producers must sell breeding stock, then drought-induced liquidation may reduce potential future revenues and profitability. Overall, surveys of agricultural credit conditions report greater weakness across areas experiencing more widespread and severe drought, especially those more concentrated in livestock production (Kauffman & Kreitman 2022).

Cattle ranchers may respond in several ways to the stressors of drought. Drought reduces the quality and amount of forage and the number of days green forage is available to cattle (UNL-NDMC 2023). Along with reduced forage, other conditions associated with drought, such as heat, light intensity, and wind, may also contribute to reduced rates of conception and weight gain, reducing the total productivity of a herd. To offset the reduction in pasture forage, ranchers may have to buy additional hay and supplements, adding additional operational costs. Another management strategy is to reduce stocking rates, or herd size, to account for reduced quantities of forage.

Although ranchers have heightened risk from drought and have numerous adaptation strategies at their disposal, they historically have not had as much access as crop producers to federal risk management tools such as livestock insurance. The federal government has two disaster assistance programs that provide compensation or benefits to eligible livestock producers who have suffered grazing losses or livestock death losses due to drought (USDA 2023a). These programs are the Livestock Forage Disaster Program (LFP) and the Livestock Indemnity Program (LIP). In recent decades, government-sponsored livestock insurance programs have been developed to protect producers against loss and provide additional options for risk management. Two insurance plans available to cattle producers include Livestock Gross Margin (LGM) and Livestock Risk Protection (LRP). LGM provides protection against loss of gross margin, and LRP provides protection against price declines (USDA 2023b). However, as of 2021, only 3 percent of the national beef cattle herd was insured against production loss due to drought and other natural disasters under LGM and LRP (Glauber 2022). In comparison, 89 percent of corn and 90 percent of soybean production are insured under federal crop insurance programs (FCA 2017).

3 Data

The dynamics of how drought influences cattle operations are unique, complex, and important for the financial health of individual farms and the agricultural sector. Therefore, in this paper we use information on drought and agricultural land use, along with data on farm production and finances, to quantify how cattle ranchers are affected by drought. We also discuss the broader market implications for the beef supply chain.

3.1 Spatial Data and Drought Risk

To construct the crop-level measure of drought exposure, we perform a geospatial merge of USDA CropScape annual data (30m grid raster) with weekly drought data from the USDM (USDAa 2022; USDM 2022). This process results in a weekly drought exposure measure by crop type (there are 100+ land-area designations, most of which are crop plantings determined from satellite imagery). We match these temporal and geospatial data to TIGERLINE shape files to aggregate up to the county-level, describing weekly drought exposure levels from 2000 to 2022. Figure 4 shows how, after matching geospatial land and drought datasets, we can identify the total share of acres in drought for land that is most important for beef cattle production, such as range land (land where cattle graze). The USDA describes range-land as areas planted in grass pasture, shrub-land, and clover/wildflowers. We also match drought exposures with areas planted in alfalfa and non-alfafa hay, which we will henceforth refer to as “hay.”

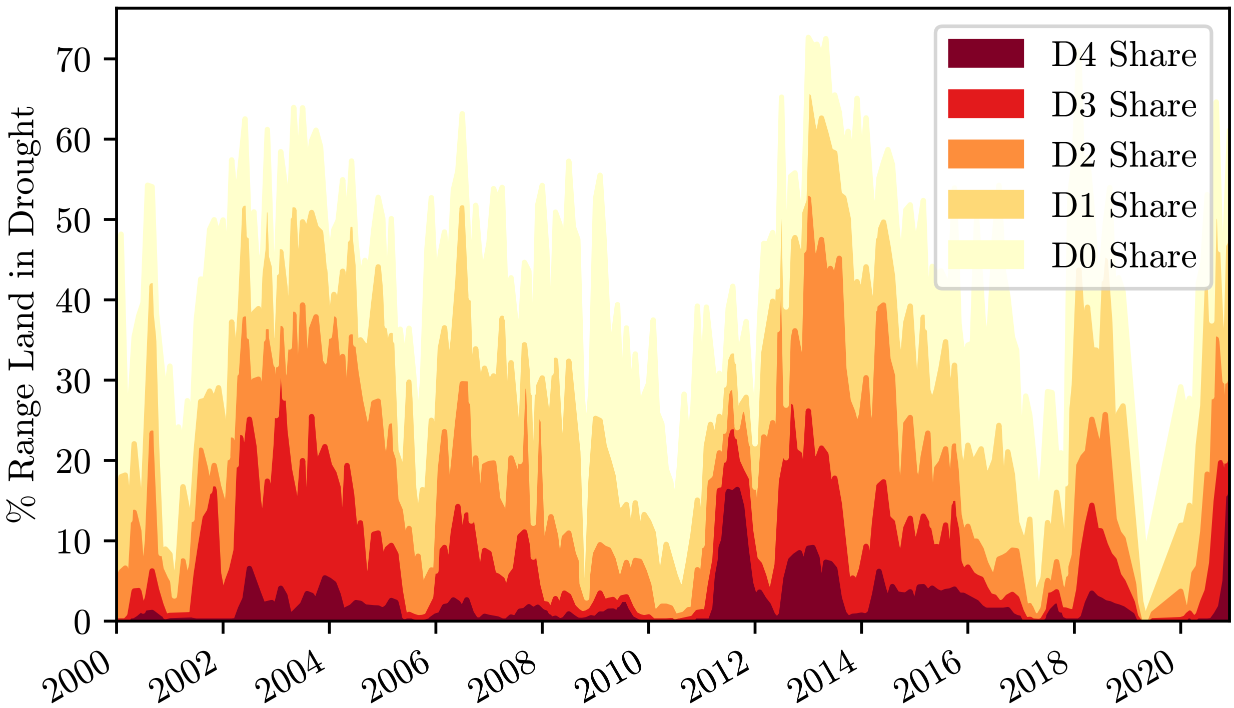

Figure 4: Area of U.S. Range-land in Drought

The USDM categorizes drought into five categories: D0 (Abnormally Dry), D1 (Moderate Drought), D2 (Severe Drought), D3 (Extreme Drought), and D4 (Exceptional Drought). With our combined data set, we are able to generate two measures of drought which we use to link drought exposures for a given county-year with outcomes for ranchers: (1) average annual drought exposure (%) by category (D0 - D4) and (2) weighted average annual drought intensity.

$$DroughtShare_{ijkt}(\%) = \sum_{w=1}^{52} \frac{Area_{ijkw}}{Area_{jkw}} * 1/52 \tag{1}$$

where:

$DroughtShare_{ijkt}$ = average drought exposure (%) for drought category (i), within a county (j), for crop (k), and year (t),

$Area_{ijkw}$ = area in drought category (i) within a county (j), for a given crop (k), for a week (w), and

$Area_{kcw}$ = area of planted in county (j), for crop (k), for week (w).

$$DroughtAve_{jkt} = \sum_{i=0}^{4} D_{ijkt} * V_i \tag{2}$$

where:

$DroughtAve_{jkt}$ = weighted average drought intensity, within a county (j), for crop (k), and year (t),

D_{ijkt} = average drought (%) for a given category (i), within a county (j), for crop (k), and year (t), and

V_i = integer value applied to drought category (D0-D4). No drought is zero and D0=1...D4=5

We use crop-specific drought exposure measures for each of our specifications. For our analysis relating directly to ranchers and cattle, we use county-level annual weighted average drought intensity and drought exposure by category (D0 - D4) for range-land (i.e., pasture and grazing land). For our analysis on hay production, we use drought exposures for land planted in hay or alfalfa. In our analysis, weighted average drought intensity is a more comprehensive summary measure for defining average drought exposure across a year. However, we also include in our analysis exposures by drought severity ("low" and "high") to capture the effects of low versus more extreme drought. We define "low" drought severity as D0-D1 drought and "high" drought severity as D2-D4 drought. These definitions are consistent with the criteria for payment outlined in the USDA's livestock forage program (USDAc 2022).

3.2 Agricultural Data

To assess the effects of drought on cattle ranchers, we create an annual county-level panel of drought exposures (section 3.1) and county-level agricultural data. We use annual county-level data on herd size, cash receipts, hay production, hay prices (at the state level), and farm income from the USDA's surveys of agriculture and the Bureau of Economic Analysis (BEA). We also use data from the USDA's five-year census of agriculture for county-level controls, such as irrigated land. Combining these data with our county drought exposures, we create an annual county-level panel spanning from 2000 to 2022. We further restrict our sample to include counties that are highly concentrated in cattle production. We define highly concentrated cattle counties as counties with cattle and calf sales that are more than 50 percent of total livestock sales (average across the sample period). Combining the county-level drought exposure data, USDA agricultural data, and our screen for cattle concentrated counties we are left with a sample that comprises 38,092 unique annual county observations, including 1,702 unique counties, covering 47 states. We include a table of data descriptions and summary statistics in the appendix (Section 8.1).

Figures 5 to 7 show heat maps of changes over two time periods for our primary explanatory variable of interest, weighted average drought intensity, and the dependent variables herd size and hay price. Although the two periods of 2018-19 and 2019-20 are only one year apart, drought intensity differs dramatically across these periods and appears correlated with annual changes in cattle herd sizes. For example, Figure 5 shows that drought intensity increased notably and spread more broadly from 2018 to 2020, particularly in the western Plains and upper northwest regions of the United States. Panel B of Figure 6 shows that herd sizes in these regions also declined. Furthermore, we see meaningful changes in state hay prices (Figure 7) that correspond to changes in drought intensity.

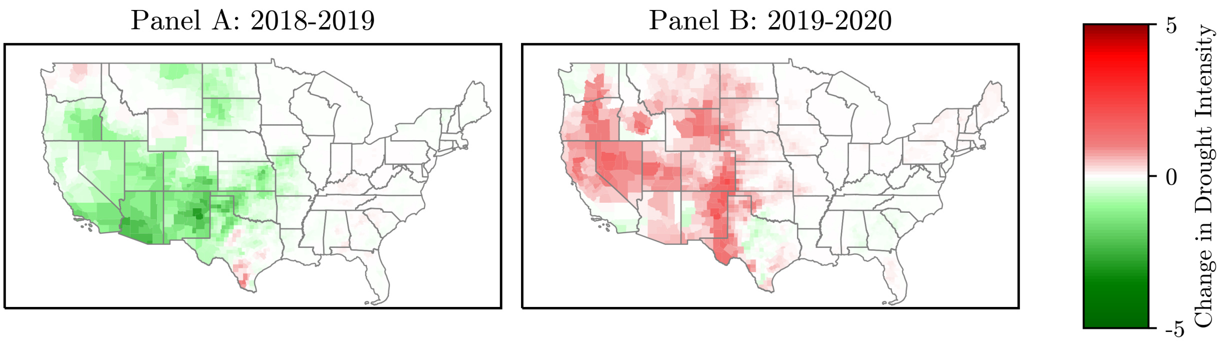

Figure 5: Weighted Average Drought Intensity Range-land (Y/Y Change)

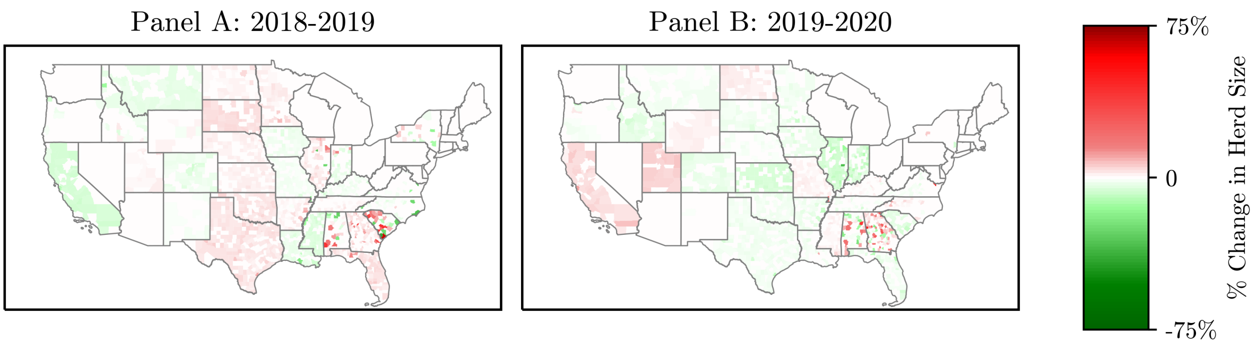

Figure 6: Change in Cattle Herd Size Y/Y(%)

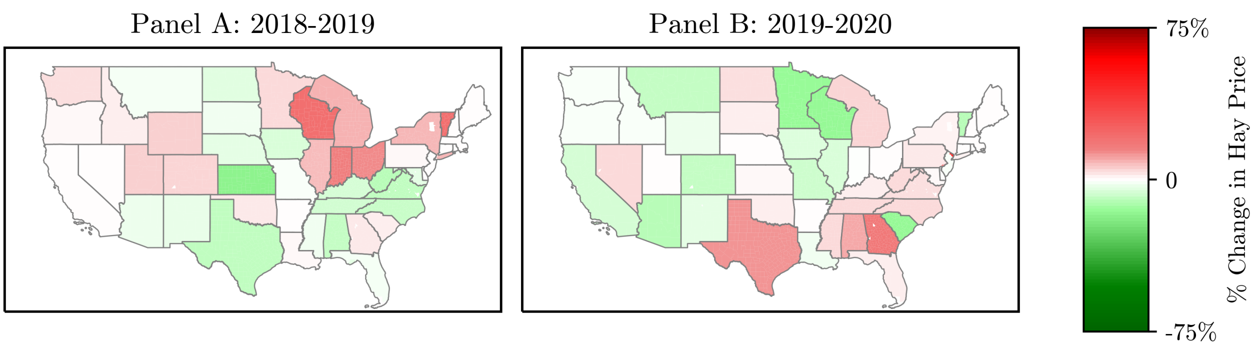

Figure 7: Change in State Hay Prices Y/Y(%)

4 Methods

We implement an ordinary least squares (OLS) panel regression framework to estimate the effect of drought exposure on ranchers. We estimate the following empirical model to investigate this relationship:

$$Y_{it} = \beta_0 + \beta_1 drought_{it} + \beta\chi + \gamma_i + \alpha_t + \epsilon_{it} \quad (3)$$

where Y_{it} denotes a series of dependent variables associated with cattle ranchers that may be impacted by drought, including herd size, hay production, hay prices, cash receipts, and income; χ is a set of control variables, notably the irrigated share of land within a county; γ_i is county fixed effects; α_t is time fixed effects; and $drought_{\text{it}}$ denotes the measure of drought exposure for a given county within a year. [2] We run two specifications for our different measures of drought exposure. Our primary specification considers weighted average annual drought (all drought categories). Our second specification considers the average annual share (%) exposed by "low" severity drought (i.e., D0-D1) and "high" severity drought (D2–D4) to delineate effects between low and high drought severity exposure (see section 3.1 for spatial methods for calculating drought exposures). We use crop-specific exposure measures. Range-land exposures are used for for rancher focused specifications: herd size, cash receipts, and income. We use drought exposures specific to hay and alfalfa production areas for hay production and hay price specifications. We use county fixed effects to control for any time-invariant characteristics that are unique to that county (such as productivity, style of ranching, and location). Time fixed effects control for factors that may affect the entire agriculture sector over time (such as commodity prices, supply and demand, or trade policy).

Additionally, we run a series of unreported robustness checks including model specifications that use various drought exposure measures (e.g., share of drought and cumulative drought), lagged drought exposures, various time-period specifications (e.g., post-USDA Livestock Forage Program), periods of high and low drought severity, and specifications with an unrestricted sample (all counties regardless of cattle concentration). Results from those specifications are not qualitatively different than our main specifications mentioned above.

[2]For all specifications we take the natural log of our dependent variables and run the models as a log-level regression.

5 Results and Discussion

Our regression models estimate the effects of drought on the cattle industry in the United States. Overall, our results point to adverse effects from drought on cattle operations. We find robust evidence that drought leads to reduced hay production as well as higher hay prices. We find some evidence that as average drought intensity increases, herd size declines. We also find that while drought is somewhat associated with increased farm revenues, likely due to a combination of herd liquidation and higher cattle prices, farm income declines with increasing drought severity.

5.1 Drought Impacts on Cattle Herd Size and Revenues

Drought does appear to influence ranchers' herd management decisions in the United States. On average, we witness a roughly 1 percent decrease in herd size for a one-unit increase in average drought intensity.

Figure 8: Drought & Herd Size

	(1) Herd Size	(2) Herd Size	(3) Herd Size	(4) Herd Size
Ave. Drght Intensity	-0.0110***	-0.0110***		
	(0.00180)	(0.00180)		
Irrigate Share (%)		-0.0177		-0.0178
		(0.0521)		(0.0521)
Low Drght Share (%)			-0.0301***	-0.0301***
			(0.00621)	(0.00621)
High Drght Share (%)			-0.0379***	-0.0380***
			(0.00739)	(0.00740)
Const.	3.772***	3.776***	3.778***	3.781***
	(0.00736)	(0.0120)	(0.00771)	(0.0122)
N	24161	24161	24161	24161
R-sq (adj)	0.0193	0.0193	0.0194	0.0194

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Specifications 3 and 4 in Figure 8 show the effects of average annual drought exposure by drought category. When comparing different levels of drought, we see that a one-unit increase in drought exposure is associated with a 3 percent decline in average herd size under low drought and a roughly 4 percent decline in herd size under high drought. According to the USDM, even the earliest stages of drought have visible effects, including slowing plant growth, damage to pastures, and possible water shortages (USDM 2022). As drought stress increases, grazing lands and feed production are impaired, weighing on a rancher's ability to maintain large herds, forcing those ranchers to right size operations in the face of challenging conditions. [3]

In general, as drought exposure increases across pasture and range land, herd sizes decline, putting downward pressure on U.S. cattle inventories. Lower cattle inventories are inversely correlated with cattle prices. For example, (Cowley & Clark 2016) find that from 2000 to 2016, the correlation between cattle inventories and cattle prices was -71 percent, suggesting that a 1 percent decline in inventories was accompanied by a 0.71 percent increase in prices. As the U.S. cattle herd declines in the midst of drought, higher cattle prices could support higher revenues for producers who choose to liquidate.

Figure 9: Drought & Revenues

	(1) Cash Receipts	(2) Cash Receipts	(3) Cash Receipts	(4) Cash Receipts
Ave. Drght Intensity	0.0121***	0.0119***		
	(0.00237)	(0.00236)		
Irrigate Share (%)		-0.137		-0.137
		(0.0756)		(0.0756)
Low Drght Share (%)			-0.00127	-0.00167
			(0.00872)	(0.00873)
High Drght Share (%)			0.0470***	0.0463***
			(0.00960)	(0.00956)
Const.	9.959***	9.982***	9.965***	9.988***
	(0.00960)	(0.0160)	(0.0101)	(0.0164)
N	36120	36120	36120	36120
R-sq (adj)	0.0984	0.0991	0.0983	0.0991

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Indeed our results indicate that cash receipts for cattle ranchers may increase temporarily as drought increases. Figure 9 shows that a one-unit increase in average drought intensity is correlated with a 1.2 percent increase in livestock revenues. As shown in Figure 8 herd liquidation

[3]Regression outputs from the log-linear models are all reported in levels. For ease of interpretation, coefficients are converted to percent changes in the text. Additionally, this herd size model uses drought exposures from the previous year due to the reporting period of cattle herds. Cattle herd data are reported in January, meaning ranchers take into account the prior year's drought in making herd management decisions. Although adjusted R-squared values in this model are low, the explained variation is consistent with previous studies estimating the effect of drought on the agricultural sector (Kuwayama et al. 2019). Additionally, after running a variance decomposition for model fixed effects (i.e., time and county), a little over 1% of variation is explained by county fixed effects and roughly 0.1% is explained by year fixed effects, thus a majority of herd-size variation is happening at the county-year level (our unit of observation). Lastly, a cattle rancher may make herd management decisions over extended periods of time (years); thus, herd management decisions may respond differently to longer duration or historical drought episodes (UNL-NDMC 2023). In Appendix section 8.2, we produce results that include lagged drought exposures. These results are not qualitatively different than the results in Figure 8. However, we do find that past year's drought and contemporaneous drought are both associated with lower herd sizes.

may increase during instances of drought. Therefore, as ranchers liquidate herds during drought, the increased quantity of cattle sold creates a temporary uptick in farm revenues. Although we do not control for the price of cattle, higher cattle prices may also contribute to the greater revenues as drought severity increases. Comparing different drought severity levels, Figure 9 specifications 3 and 4 show that livestock revenues tend to increase when ranchers are exposed to more severe drought. We do not find evidence that livestock revenues increase in low drought severity. However, livestock revenues increase roughly 5 percent when the share of pasture land exposed to high drought severity increases by one-unit, consistent with herd liquidation in more severe drought categories.

5.2 Hay Production and Prices

Although drought may have a positive effect on farm revenues, it also can have significant negative effects on hay production, as shown by the results in Figure 10.[4] Overall, a one-unit increase in average drought intensity on land where hay is produced can reduce hay production by 12 percent. In general, as drought severity increases from low to high drought severity, hay production declines 13 percent to 38 percent for a one-unit increase in drought exposure. Irrigation does not have a significant effect on hay production, which could be because irrigation is less common for hay than for other feed crops. Limited use and influence of irrigation on land used to produce hay could also help explain why the effects of drought are so large and significant for hay production. Lower supplies of hay in the midst of drought contribute to reduced feed availability, likely driving up both feed costs and operating costs for ranchers.

Drought tends to reduce the supply of hay produced and we also find that hay prices are higher in areas experiencing drought. As show in Figure 11, drought has a significant effect on hay prices and explains much of their variation.[5] In the first regression, a one-unit increase in

[4]For our hay production specification, the county sample is further restricted to USDA census years only (every five years), as those are the only years that county hay production is reported.

[5]The hay price specification follows a similar methodology to other specifications. However, we use an annual

Figure 10: Drought & Hay Production

	(1) Hay Prod.	(2) Hay Prod.	(3) Hay Prod.	(4) Hay Prod.
Ave. Drght Intensity	-0.123***	-0.123***		
	(0.00572)	(0.00572)		
Irrigate Share (%)		0.0651		0.0618
		(0.0759)		(0.0759)
Low Drght Share (%)			-0.145***	-0.145***
			(0.0220)	(0.0220)
High Drght Share (%)			-0.481***	-0.481***
			(0.0227)	(0.0227)
Const.	10.50***	10.49***	10.50***	10.49***
	(0.00863)	(0.0154)	(0.00992)	(0.0163)
N	6028	6028	6028	6028
R-sq (adj)	0.253	0.253	0.252	0.252

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

average annual drought intensity across land in hay and alfalfa production results in a roughly 5 percent increase in hay prices. In addition, the simple model explains much of the variation in state-level hay prices without including any additional explanatory variables.

Figure 11: Drought & Hay Prices

	(1) Hay Price (y/y)	(2) Hay Price (y/y)	(3) Hay Price (y/y)	(4) Hay Price (y/y)
Ave. Drght Intensity(y/y)	0.0543***	0.0543***		
	(0.00952)	(0.00953)		
Irrigate Share (%)		-0.00689		-0.0144
		(0.0813)		(0.0842)
Low Drght Share (y/y)			0.105**	0.105**
			(0.0344)	(0.0346)
High Drght Share (y/y)			0.196***	0.196***
			(0.0345)	(0.0345)
Const.	0.104*	0.105*	0.113*	0.115*
	(0.0425)	(0.0429)	(0.0439)	(0.0451)
N	7107	7107	7107	7107
R-sq (adj)	0.414	0.414	0.414	0.413

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In general, higher levels of drought severity have larger effects on hay prices. The third specification in Figure 11 shows the effects of average annual share of hay and alfalfa production exposed to low and high drought severity. For a 1 percent increase in drought exposure, hay prices increase by roughly 0.11 percent under low drought severity and 0.20 percent under high drought severity.[6]

state panel (with state and time fixed effects), as hay prices are only reported annually at the state level. We also run the model in log changes (to avoid non-stationary issues for hay prices).

[6]We run an unreported specification for feed expenditures, finding some limited evidence that feed expenditures rise, as drought severity increases. With hay production (a primary feed) declining as drought severity increases, it stands to reason that feed expenditures would increase along with drought severity. However, there may be offsetting changes between rising feed costs (as shown in the hay price specification, Figure 11), lower feed production (Figure 10), and potentially lower feed demand due to herd liquidation (Figure 8), during drought episodes. Rising feed costs and lower feed demand (at the county-level) may partially off-set each other, leading to generally weak evidence that overall feed expenses increase during periods of drought. In future work, some

5.3 Farm Earnings

Following our results on hay production and costs, we find that farm earnings in counties concentrated in cattle production decline as drought severity increases.[7]

Figure 12: Drought & Farm Earnings

	(1) Farm Earnings	(2) Farm Earnings	(3) Farm Earnings	(4) Farm Earnings
Ave. Drght Intensity	-0.0387***	-0.0389***		
	(0.00979)	(0.00979)		
Irrigate Share (%)		-0.210		-0.213
		(0.250)		(0.250)
Low Drght Share (%)			-0.118**	-0.118**
			(0.0363)	(0.0363)
High Drght Share (%)			-0.155***	-0.156***
			(0.0382)	(0.0382)
Const.	9.145***	9.176***	9.174***	9.205***
	(0.0369)	(0.0529)	(0.0394)	(0.0548)
N	14180	14180	14180	14180
R-sq (adj)	0.106	0.107	0.107	0.107

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 12 shows that in the first two specifications, farm income declines by 4 percent, on average, after a one unit increase in drought severity. In the third specification, we see that the magnitude of declines in farm income are higher when drought conditions are more severe. Farm income declines by roughly 11 percent when the share of pastureland exposed to low severity drought increases by one unit and by 14 percent when the share of pastureland exposed to high severity drought increases by one unit.

6 The Broader Market Implications of Drought

The results of this study show that drought has a negative effect on the size of cattle herds across counties in the United States. In fact, Figure 13 (Panel A) shows that aggregate U.S. cattle inventories decline in almost every year in which 10 percent or more of range-land is in D2 to D4 drought. Lower inventories of beef cows mean a reduced supply of cattle in the supply

of this ambiguity could be resolved with better information on annual county-level quantities of feed purchased (feed demand) or feed expenditures attributed solely to ranchers.

[7]For our farm earnings specification, the sample is restricted to counties that have both a high cattle concentration (i.e., cattle sales > 50 percent of livestock sales) and high livestock concentration (i.e, livestock sales > 50 percent of total sales). A majority of counties concentrated in livestock activity are also concentrated in cattle production. Our county-level farm earnings data are for all farm earnings (e.g., crops and livestock) and thus, it is necessary to apply this dual restriction to focus the analysis on predominantly cattle producing counties.

chain. Fewer cattle in the supply chain ultimately results in lower domestic beef production relative to years with less severe, or less wide spread, drought.

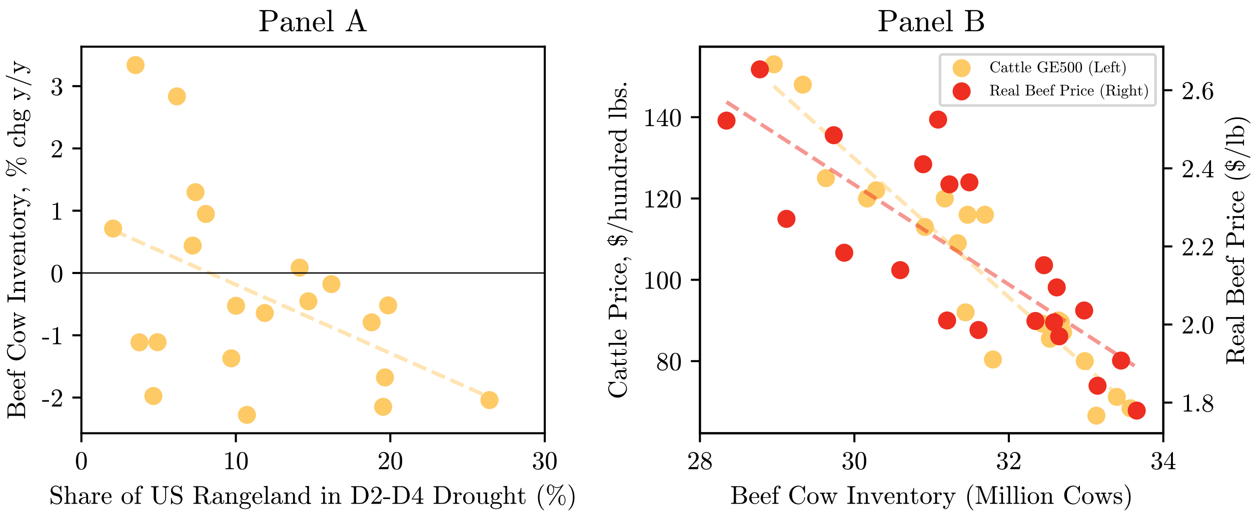

Figure 13: Drought, Cattle Inventory, and Beef Prices

As producers shrink cattle herds in the midst of drought, lower cattle inventories could contribute to higher beef prices for consumers. Figure 13 (Panel B) shows the relationship between beef cow inventories and prices for cattle and beef. As cattle inventories decline, the price paid to ranchers for their cattle increases.[8] However, Figure 13 (Panel B) also shows that retail prices for beef increase as beef cow inventories decline. In fact, the correlation coefficient between beef cow inventories and retail beef prices is -0.65 – A 1 percent decline in beef cow inventories is typically associated with a 0.65 percent increase in the price consumers pay for beef at the grocery store.

The COVID-19 pandemic showed how shocks to supply chains can have dramatic and persistent effects on both producers and consumers. Similarly, increased climate variability could contribute to more frequent, severe, and persistent drought, which also has the potential to shock supply chains. Therefore, although this paper mainly explores the effects of drought on cattle producers, further work could be done to better understand the effects of drought on consumers of beef and other livestock products.

[8]Data for retail beef prices are from (USDA 2023c) This follows our results for farm revenues in the previous section, where farm revenues increased as drought intensified.

7 Conclusion

Despite increasing concerns about severe and persistent drought across cattle production areas of the United States, few studies have quantified how drought affects the physical and financial aspects of cattle production. In this paper, we estimate the effects of drought on cattle herd sizes, hay production, farm revenues, and income. We find evidence that drought leads to greater herd liquidation, with average herd sizes dropping by 1 percent for a one-unit increase in drought intensity. Herd liquidation is also more pronounced in higher severity drought. We find that increasing drought severity results in lower hay production (12 percent lower hay production for every one-unit increase in drought severity) and higher hay prices (5 percent increase in average hay prices for every one-unit increase in drought severity). Although revenues for cattle ranchers increase with drought severity (due to herd liquidation), farm earnings tend to decline with drought – earnings drop by 4 percent on average with every one-unit increase in average drought intensity. Furthermore, farm earnings declines are more pronounced in areas experiencing more severe drought – 11 percent declines in low drought compared with 14 percent in high drought.

Our results for the effects of drought on farm income for cattle ranchers differ from previous studies that show no significant effects from drought on the incomes of crop producers. These results draw attention to the economic risks associated with drought for cattle ranchers, who already face relatively narrower profit margins and higher costs than other agricultural producers (Cowley 2021). As drought severity increases, reduced farm income could result in depressed farm financial positions for ranchers and weaker agricultural credit conditions in areas highly concentrated in cattle production.

Our analysis focuses specifically on the effect of increasing drought intensity on cattle production and components of farm income. However, our spatial data-matching framework can also be used to study other types of relationships between drought and agriculture. Combining

USDM spatial data with the USDA CropScape data layer allows for further analysis of crop-specific exposure to drought at the county-level. For example, we find that drought exposure can explain much of the variation in hay production and price when we match geospatial data for hay production areas with USDM drought exposure.

Moreover, future work could explore the effects of drought on cattle and beef markets, specifically how the pass-through from herd liquidation to lower cattle supplies could affect future consumer beef prices. Future work could also quantify the effectiveness of livestock insurance and disaster assistance programs on the financial condition of farms impacted by drought.

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8 Appendix

8.1 Data Descriptions and Summary Statistics

Variable	Units	Source	Geo.	Freq	Mean	St. Dev.	Min	Max	N
WA drought intensity	Unitless, 0 to 5, rangeland	USDM	County	A	0.7760	0.9280	0.0	5.0	61361
WA drought intensity	Unitless, 0 to 5, hay	USDM	County	A	0.7660	0.9210	0.0	5.0	60145
D0, abnormally dry	% of range land	USDM	County	A	16.8000	13.7500	0.0	99.0	61361
D1, moderate drought	% of range land	USDM	County	A	10.3000	13.1900	0.0	99.9	61361
D1, moderate drought	% of hay acres	USDM	County	A	10.2700	13.4490	0.0	100.0	60145
D2, severe drought	% of range land	USDM	County	A	6.5730	12.5160	0.0	99.8	61361
D2, severe drought	% of hay acres	USDM	County	A	6.4720	12.6470	0.0	100.0	60145
D3, extreme drought	% of range land	USDM	County	A	3.5190	10.1900	0.0	99.9	61361
D3, extreme drought	% of hay acres	USDM	County	A	3.4270	10.2380	0.0	99.9	60145
D4, exceptional drought	% of range land	USDM	County	A	1.2800	6.7060	0.0	100.0	61361
D4, exceptional drought	% of hay acres	USDM	County	A	1.2181	6.6034	0.0	100.0	60145
Beef cow herd size	Number	USDA-S	County	A	12461.0	12790.0	0.0	182000.0	41805
Farm ops. w/cattle prod.	Number	USDA-C	County	5Y	245.0	246.0	1.0	2458.0	61398
Average herd size	Beef cows per operation	USDA-S	County	A	52.5	54.87	0.0	1578.0	41805
Cattle sales	Thousand dollars	USDA-C	County	5Y	19800.0	59500.0	2.0	1370000.0	6999
Hay prices	Dollars per ton	USDA-S	State	A	112.0	39.6	41.5	258.0	882
Hay production	Tons	USDA-C	County	5Y	43161.0	65785.0	12.0	2160999.0	6999
Irrigated acres	% of total farmland	USDA-C	County	5Y	17.0	15.97	0.0	100.0	61398
Livestock revenues	Dollars	BEA	County	A	54200.0	114636.0	0.0	3146184.0	61398
Farm Income	Dollars	BEA	County	A	24938.0	75291.0	-59778.0	2593341.0	61398

*Abbreviations - WA: Weighted Average, USDA-S: USDA Survey Data, USDA-C: USDA Census Data, A: Annual

8.2 Drought and Herd Size with Lagged Drought Exposure

Figure 14: Drought & Herd Size

	(1) Herd Size	(2) Herd Size	(3) Herd Size	(4) Herd Size
Ave. Drght Intensity	-0.0110***	-0.00797***		
	(0.00180)	(0.00158)		
Ave. Drght Intensity t-1		-0.00964***		
		(0.00148)		
Irrigate Share (%		-0.0222		-0.0223
		(0.0508)		(0.0507)
Low Drght Share (%)			-0.0301***	-0.0206***
			(0.00621)	(0.00574)
Low Drght Share (%) t-1				-0.0331***
				(0.00645)
High Drght Share (%)			-0.0379***	-0.0304***
			(0.00739)	(0.00641)
High Drght Share (%) t-1				-0.0315***
				(0.00605)
Const.	3.772***	3.772***	3.778***	3.782***
	(0.00736)	(0.0117)	(0.00771)	(0.0125)
N	24161	22826	24161	22826
R-sq (adj)	0.0193	0.0225	0.0194	0.0230

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$