# Drought Exposure and the Livestock Forage Disaster Program: Impacts on U.S. Cattle Populations

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# Abstract

This paper examines the impacts of drought conditions, as defined by the U.S. Drought Monitor (USDM), on U.S. beef cattle inventories between 2000 and 2023. Using a county-level panel dataset and fixed effects models that exploit geographical and time variation in drought exposure, we estimate how additional weeks of various drought severity levels affect annual cattle populations. We find that weeks spent in extreme (D3) and exceptional (D4) drought significantly reduce herd sizes, with D3 associated with an 11-basis point decline and D4 with a 27-basis point decline per week. We assess the interaction between prolonged drought and participation in the Livestock Forage Disaster Program (LFP), a federal disaster assistance program. Results show that LFP payments—especially the 4-month and 5-month tiers triggered by extended D3 or D4 drought—partially offset the effects of drought on herd retention. Ultimately, our analysis provides empirical evidence that persistent, high-severity drought reduces cattle inventories, but targeted disaster assistance can mitigate these impacts.



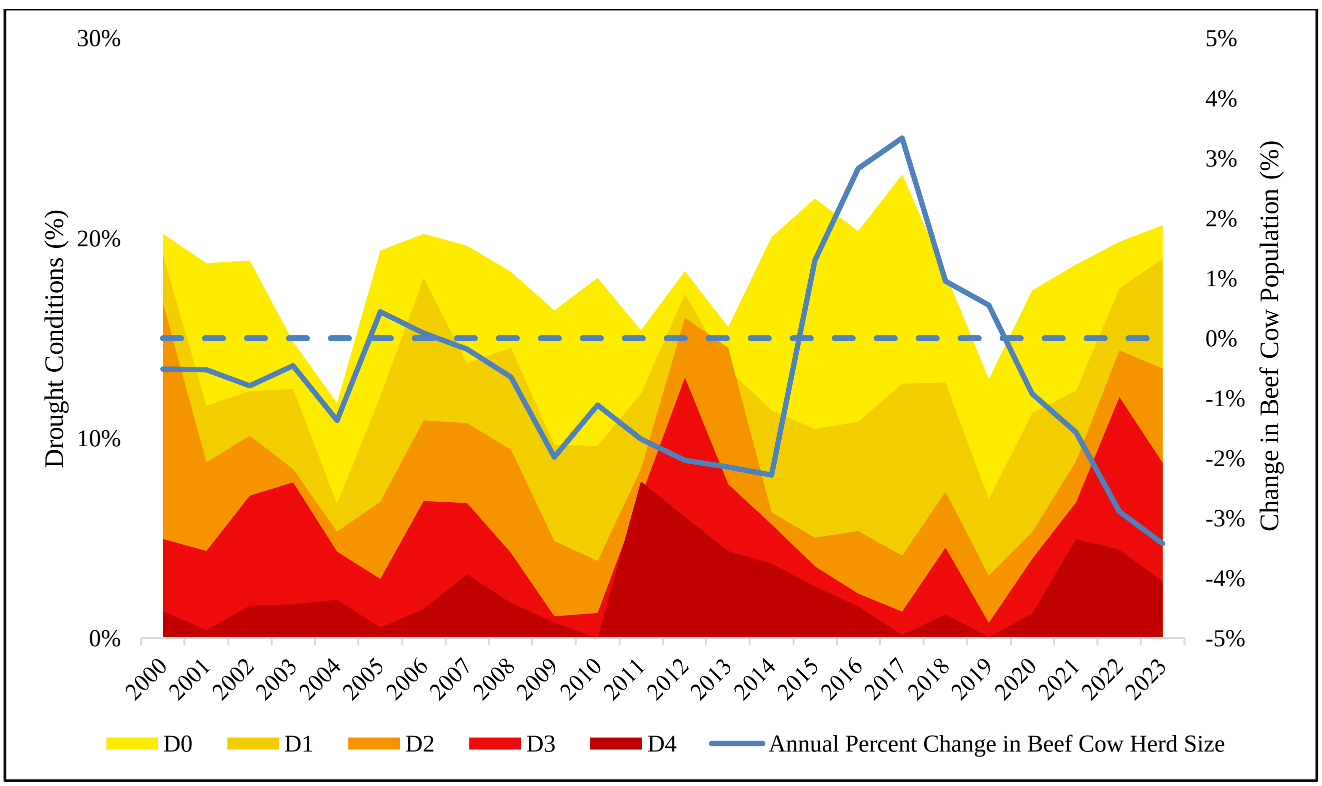
*JEL Codes: Q18 (Agricultural Policy), Q54 (Climate; Natural Disasters), Q12 (Micro Analysis of Farm Firms, Farm Households, and Farm Input Markets)*

Keywords: Drought, Livestock Forage Disaster Program, Cattle

# 1 Introduction

Droughts have become an increasingly critical force shaping U.S. beef cattle production. As of January 2024, there were only 28.2 million beef cows nationally—the lowest level since 1961 (USDA NASS). While some of this decline reflects long-term trends in the cattle cycle, drought conditions exacerbate herd reductions by raising feed costs and compromising pasture quality (Rodziewicz et al. 2023). An estimated 186 million hectares of grazing land experience dryness each year (Maher et al. 2021), with more than 60% of the United States enduring at least moderate drought (D1) in 2023 (USDM 2024). Climate models further warn that drought frequency and severity will intensify (IPCC 2023), imposing added heat stress on cattle (Thornton et al. 2023) and further tightening producer margins.

Figure 1: Annual Drought Conditions and Change in Cattle Populations 2000 to 2023




Source: USDM, USDA NASS data.

Much of the existing literature on drought has focused on its impact on crop yields and the resulting market disruptions (Kuwayama et al. 2018; Schlenker and Roberts 2009). In contrast, relatively fewer studies have examined how drought persistently affects cattle inventories and how federal assistance programs may help buffer these effects. Research indicates that beef cows, in particular, are especially vulnerable to prolonged dryness because reduced forage availability and degraded pasture quality directly elevate production costs. As a result, ranchers are often compelled to cull herds or postpone expansions (Rodziewicz et al. 2023), which diminishes future cattle supplies and risks downstream price spikes. Indeed, a 1% decline in beef cow populations is associated with a 0.65% increase in retail beef prices (Rodziewicz et al. 2023), and reflecting these mounting pressures, the national average price of ground beef recently reached a record $5.67 per pound in September 2024 (St. Louis Federal Reserve 2024). This dynamic underscores the importance of investigating both the persistent effects of drought on cattle populations and the potential mitigating role of public assistance programs, such as the Livestock Forage Disaster Program (LFP).

Meanwhile, the LFP, formally established in 2014, has emerged as the primary federal safety net against drought-induced forage losses, outpacing smaller-scale initiatives like ELAP (Emergency Assistance for Livestock). LFP grants up to 60% of monthly feed costs for affected producers, with the possibility of receiving up to 5 months of coverage based on the severity and duration of drought conditions (LFP Fact Sheet 2023). Previous research (Hrozencik et al. 2024) has largely focused on counties crossing minimal thresholds for a single month of payments. However, the efficacy of higher-tier or multi-month coverage under extended drought conditions remains less examined.

Against this backdrop, this paper compiles annual county-level cattle population data from the USDA NASS and merges these data with weekly U.S. Drought Monitor (USDM) classifications spanning 2000 to 2023. Using a two-way fixed-effects panel design, I link the severity and persistence of drought conditions—particularly at higher intensities such as D3 (“extreme”) and D4 (“exceptional”)—to changes in cattle inventories. I then incorporate LFP eligibility tiers to assess how federal disaster assistance moderates herd declines. The findings provide new insights into whether multi-month LFP coverage effectively prevents or delays herd liquidation under the harshest drought scenarios. These insights are critical for policymakers tasked with stabilizing cattle inventories and maintaining a resilient beef supply as market pressures escalate.

The remainder of the paper proceeds as follows. Section 2 reviews existing literature on drought’s physical and economic impacts on cattle, outlines the USDM classification system, and discusses previous research on federal disaster programs, with an emphasis on LFP. Section 3 details the data, including county-level cattle inventories, USDM drought designations, and LFP payment records. Section 4 outlines the empirical framework, detailing the baseline model and subsequent specifications that incorporate variations in drought severity, duration, and policy coverage tiers. Section 5 presents the results, comparing estimates across these alternative modeling approaches and highlighting how LFP coverage interacts with drought intensity to influence herd decisions. Section 6 offers concluding remarks.

## 2 Literature Review

This section first surveys the physical and economic effects of drought on agricultural outcomes, specifically cattle, introduces the U.S. Drought Monitor framework integral to measuring drought severity, and finally reviews prior work on federal disaster assistance programs, focusing on the LFP.

### 2.1 Physical Impacts of Drought

Researchers have documented the physical impacts of drought: it impairs cattle productivity, degrades grazing land, and reduces crop production (Thornton & Herrero, 2022; USGCRP, 2018; Lobell et al., 2013). Reduced forage availability and poor forage quality during drought lead to lower feed intake, weight loss, and weaker reproductive performance in cattle (Thornton & Herrero, 2022). These effects worsen when animals face sustained heat stress and limited water access, forcing producers to adjust herd size or supplement with expensive feed (Thornton & Herrero, 2022). Drought also weakens the land itself. Most U.S. forage systems rely on rainfall, and when soil moisture declines, pasture productivity falls (USGCRP, 2018). The U.S. Global Change Research Program (2018) finds that drought reduces the number of grazing days across much of the southern Plains and western states, which hold a large share of the national herd. Recovery is often slow: long droughts can damage root systems, accelerate erosion, and encourage invasive species that reduce the nutritional value of forage (USGCRP, 2018). Heat intensifies these pressures. Lobell et al. (2013) show that crop yields fall sharply on extremely hot days, even when rainfall is normal. Their findings, while focused on maize, point to broader risks for shallow-rooted forage crops under high heat (Lobell et al., 2013). These conditions increasingly overlap with drought, amplifying feed stress in cattle systems (Thornton & Herrero, 2022). Climate projections suggest these patterns will continue. The Intergovernmental Panel on Climate Change (2023) expects more frequent extreme drought and heat events in key livestock-producing regions. As these risks compound, the potential for agricultural production and financial losses grows (IPCC, 2023).

### 2.2 Economic Impacts of Drought

` Major droughts often impose billions of dollars in agricultural losses, reverberating through regional and national economies (Riebsame et al., 1991; Wheaton et al., 2008; Horridge et al., 2005). Riebsame et al. (1991), for instance, documented substantial crop failures and yield shortfalls during the 1988–1989 U.S. drought, estimating losses near $15 billion when factoring in production declines and market disruptions. Yet the cattle sector faces distinct challenges. Unlike row-crop producers, who may rely on crop insurance or switch to less water-intensive varieties, cattle ranchers, who are rarely insured, depend on forage quality—an aspect that plummets under prolonged dryness and heat (Rodziewicz et al., 2023). With fewer insurance option, producers may be forced to liquidate herds, which can take years to rebuild.[1] Hence, they often incur deeper and more lasting financial setbacks compared to other agricultural industries.

### 2.2.1 U.S. Drought Monitor

A key methodological choice in drought research is how to capture dryness. While some studies (e.g., Patalee & Tonsor, 2021) rely on simple precipitation deviations, Kuwayama et al. (2018) demonstrate that the U.S. Drought Monitor (USDM) can more holistically reflect drought stress by integrating precipitation percentiles, soil moisture data, streamflow measures, and expert inputs into weekly intensity designations (D0–D4). Although Kuwayama's analysis centered on crop yields, the USDM is equally relevant for livestock research—especially since the LFP uses USDM thresholds to trigger drought relief. Moreover, Kuwayama's emphasis on drought duration—treating each additional week of dryness as an incremental source of yield loss—provides a compelling framework for cattle-focused studies. Prolonged spells of D2 ("severe drought") or above can rapidly erode forage availability, forcing herd liquidation and undermining farm income. By tracking cumulative and consecutive weeks of drought intensity as classified by the USDM, this paper aligns with existing crop-yield literature.

### 2.2.2 Approaches to Cattle Outcomes

[1]The gestation period of cattle is 283 days (9 months). Heifers generally have their first calf at 2 years of age, so rebuilding is a slow process.

When examining drought's financial impact on cattle operations, researchers commonly focus on feed prices, hay production, farm revenues, and herd inventories as outcomes (Rodziewicz et al., 2023). Rodziewicz et al. (2023) adapt Kuwayama's crop-focused design to the cattle context, assembling a county-level panel (2000–2022) that regresses annual average drought intensity on herd size, hay production, hay prices, and farm income. Rodziewicz et al. (2023) find that a 1 percent increase in low-severity drought exposure reduces average herd size by about 3 percent whereas the same 1 percent increase in high-severity drought cuts average herd size by about 4 percent.

A closer look at hay highlights the pathways through which drought heightens production costs. Rodziewicz et al. (2023) find that each one-unit increase in annual average USDM drought intensity drives a 12 percent drop in hay production and a 5 percent surge in hay prices; they further show that a 1 percent increase in drought exposure can elevate hay prices by 0.11 percent under lower severity and 0.20 percent under higher severity. Kuwayama et al. (2018) document yield reductions of 0.1–1.2 percent (up to 8 percent under extreme drought in dryland counties in the Midwest) per additional week of D2 or worse conditions—though they focus on crop yields rather than feed prices. While Deschênes and Greenstone (2007) and Schlenker and Roberts (2009) discuss how global production shifts might influence prices, they do not measure feed-price outcomes directly. Overall, these findings underscore that hay and feed price inflation transmits drought's economic impact to cattle producers. Accordingly, this paper does not control for hay and feed prices.

By contrast, irrigation is often regarded as a structural factor—rooted in water rights or infrastructure—that may or may not alleviate drought's effects on cattle. Hrozencik et al. (2024) and Rodziewicz et al. (2023) control for irrigated acreage when assessing the LFP's influence on cattle, Rodziewicz et al. (2023) detect no meaningful moderation from irrigation in explaining farm revenue or herd outcomes. Kuwayama et al. (2018), however, find that irrigated counties exhibit smaller yield penalties in dryland areas, lowering the reduction crop yield to 0.1 percent to 0.5 percent as compared 0.1 percent to 1.2 percent in non-irrigated counties. This implies some buffering capacity for certain crops. Given these mixed results, we follow broader practice in controlling for irrigation status, recognizing it as a baseline characteristic that can shape drought's mitigation for cattle operations.

In summary, this paper both differs from and builds on Rodziewicz et al. (2023) by disaggregating drought into all five USDM severity levels (D0–D4) and focusing on cattle populations rather than multiple farm measures. Simultaneously, it aligns with Kuwayama et al. (2018) by capturing cumulative and consecutive weeks of drought rather than relying solely on annual county fractions in drought. Perhaps most crucially, we also control for LFP payments, a policy dimension that previous studies have not fully addressed, thereby offering a more complete picture of how drought, feed costs, herd decisions, and disaster assistance jointly affect cattle operations. With this methodological groundwork in place, we now turn to the LFP itself.

### 2.3 Livestock Forage Disaster Program

Despite serving as the primary Federal mechanism for offsetting drought-induced forage losses in U.S. livestock systems over the past decade, the LFP has received far less academic scrutiny than other major agricultural risk-management tools, such as the Federal Crop Insurance Program **(**Annan & Schlenker, 2015; Wang et al., 2021; Regmi et al., 2023).The first large-scale empirical examination of LFP's stocking impacts is that of Hrozencik et al. (2024), who use a matching approach, looking at years only after the advent of the program (2014 to 2023). In their paper, "treated" counties are those that cross the consecutive weeks of D2 drought threshold just enough to trigger 1 month of payments, while "control" counties experience nearly similar drought but do not qualify. They find no significant difference in subsequent beef-cattle inventories between these treatment and control counties, implying that a single month of LFP payments does not measurably affect aggregate herd-retention outcomes.

Hrozencik et al. (2024) also estimate potential future LFP spending under various greenhouse gas emission scenarios, projecting substantial increases in annual Federal expenditures (up to 100% or more above recent averages) by 2100 if drought severity intensifies.

While these findings shed light on 1-month LFP payments, questions remain regarding outcomes when drought triggers multiple months of coverage. Moreover, the matching approach utilized by Hrozencik et al. (2024) differs from the fixed-effects panel strategies used by Kuwayama et al. (2018) and Rodziewicz et al. (2023). By incorporating a two-way fixed-effects panel framework and expanding the panel range to the years before the widespread adoption of the program in 2014, this paper can explore longer durations of LFP eligibility (e.g., three to five months of assistance) and compare drought intensity across a broader range of USDM severity categories (D1–D4). In doing so, it extends the current literature by examining both the severity and duration of drought conditions and whether multi-month LFP support affects cattle retention more strongly than a single month of assistance.

## 3 Data

This paper integrates multiple USDA data sources with weekly U.S. Drought Monitor (USDM) designations to construct a comprehensive county-level panel from 2000 through 2023. Annual cattle inventory counts come from the USDA's National Agricultural Statistics Service (NASS), while LFP information—reporting up to five months of disaster payments—originates from the USDA Farm Service Agency (FSA). By merging these with USDM drought severity categories (D0 to D4) on a week-by-week basis, I assemble a balanced dataset of counties over time, discarding counties without continuous coverage. This approach ensures consistency despite initial gaps in reporting, ultimately yielding 22,752 county-year observations across 948 counties and 24 years.

Because cattle population data are annual (as of the end of the year) and drought is measured weekly, a key challenge arises in translating short-term fluctuations in drought severity into annual variables relevant to ranchers' herd decisions. Simple, aggregated metrics risk overlooking consecutive-week spells, which could be disproportionately damaging. As a result, I build different annual measures that capture not only the total number of drought weeks, but also the longest stretches of drought. To measure drought severity and duration, I employ two strategies aligned with both producer decision-making and LFP eligibility rules. First, I count the total number of weeks a county experiences each level of drought (D0 through D4) in a given year—our baseline cumulative specification. Second, I construct "maximum run" variables that capture the longest uninterrupted spell of each drought level or worse, testing whether consecutive drought exposure better explains herd outcomes than total weekly counts. The following sections provide additional detail on these measures and their application in the regression framework.

### 3.1 USDA Cattle Population Data

This paper uses county-level beef cattle inventory estimates from the USDA's National Agricultural Statistics Service (NASS) spanning 2000–2023 (USDA, NASS 2024). Although the NASS data include both beef and dairy herds, the analysis focuses specifically on beef cows, [2] the core of the beef industry's breeding stock and thus the most direct measure of cattle population changes over time. This measurement is consistent with previous literature (Rodziewicz et al. 2023).

While one might consider weekly cattle slaughter sales to capture very short-term adjustments, these data do not reflect the strategic, longer-term herd management decisions that producers make annually, so combining yearly aggregated cattle inventories with drought conditions aggregated over the

[2] Cows are mature female cattle.

year—focusing on breeding herds (cows)—offers a more appropriate lens through which to study the broader implications of drought on cattle populations.

A number of states are not represented in the data—several states are excluded due to incomplete or inconsistent reporting[3]—additionally Hawaii and Alaska are excluded because they collectively accounted for only 0.06% of the U.S. cattle population in the 2017 NASS census, and their limited coverage and reporting inconsistencies would not contribute meaningfully to national-level trends. As a result, after these exclusions and the removal of suppressed county-year observations, 2,758 counties remain, producing 47,568 county-year observations. Moreover, due to NASS disclosure rules, some county-level data are suppressed to protect the privacy of individual operations, particularly those with smaller herd sizes. However, not all counties report data every year; only 948 counties (about 35% of the sample) provide complete information across all 24 years, forming a fully balanced panel.

Because a key objective is to examine drought impacts consistently over time, the main regressions rely on this balanced panel. Although this restriction roughly halves the number of counties, these 948 counties represent about 60% (≈11 million head) of the post-exclusion sample that is 65% of the national beef cow population. This approach minimizes shifts in sample composition that could bias estimates and provides a stable backdrop for analyzing drought severity and policy interventions such as the LFP.

[3] Arizona, Connecticut, Delaware, Maine, Maryland, Massachusetts, Michigan, Nevada, New Hampshire, New Jersey, Ohio, Pennsylvania, Rhode Island, Vermont, Washington, West Virginia, Wisconsin, and Wyoming.

Table 1: Summary Statistics for Cattle Populations per County

| | |
|---|---|
| Observations | 22,752 |
| Mean | 12,922.53 |
| Std. Dev. | 12,059.04 |
| Min | 100 |
| Max | 103,000 |
| 1% | 500 |
| 5% | 1,100 |
| 10% | 1,700 |
| 25% | 3,900 |
| **50%** | **9,800** |
| 75% | 18,000 |
| 90% | 28,000 |
| 95% | 36,500 |
| 99% | 54,000 |
| Skewness | 1.903094 |
| Kurtosis | 8.66086 |

The distribution of herd sizes in this balanced subset is notably skewed. While a typical county may hold between 3,900 and 18,000 head, some outliers exceed 103,000 This pattern aligns with broader national data, where operations with over 500 cows constitute only 2% of farms but account for nearly 18% of the total beef-cow inventory (Table 2). Such concentration suggests that drought impacts, and the effectiveness of policy responses might be disproportionately important among larger operations.

Table 2: U.S. Cattle Operations by Herd Size

| | 20 – 49 cows | 50 – 99 cows | 100 – 249 cows | 250 – 499 cows | ≥500 cows |
|---|---|---|---|---|---|
| Percent of farms | 48 | 27 | 18 | 6 | 2 |
| Percent of beef cows | 16 | 19 | 27 | 20 | 18 |

(Source: USDA 2017 Census of Agriculture)

### 3.2 FSA LFP Disaster Program Data

3.2.1 Program Overview and Timeline

The LFP provides financial assistance to livestock producers who suffer significant forage losses due to drought or fire. Initially authorized in 2008 as an insurance-based system, LFP remained relatively small through 2013, averaging about $94 million in annual outlays—roughly 8 percent of the $1.16 billion average distributed from 2014 to 2023. Beginning with the 2014 Farm Bill, LFP was made permanent and substantially expanded; program outlays surged, and the USDA FSA began publishing comprehensive county-level data on USDM triggers, indicating 0–5 months of LFP eligibility per county-year.

Although 2014 included retroactive lump-sum payments for earlier droughts (2011–2013), these do not affect a county's current-year months of eligibility. Indeed, pre-2014 records provide no consistent county-level measure of drought triggers. Hence, all LFP variables are set to zero for 2000–2013 and vary meaningfully only from 2014 onward.

Because the USDA does not separately track the fraction of LFP payments going to cattle producers, focusing on months of LFP eligibility (rather than total dollar outlays) is a more reliable indicator for this paper.

### 3.2.2 Eligibility

Under LFP, a county can receive 1–5 months of feed-cost coverage, determined by USDM drought levels during county specific grazing periods:

- 1 month of payments: At least eight consecutive weeks of severe drought (D2).
- 3 months of payments: At least one week of extreme drought (D3).
- 4 months of payments: Four or more weeks of extreme drought (D3) or at least one week of exceptional drought (D4).
- 5 months of payments: Four or more weeks of exceptional drought (D4).

LFP payments cover 60% of monthly per-animal feed costs. Additionally, livestock sold due to drought within the two years preceding current production are eligible for 80% of monthly feed costs (LFP Fact Sheet, 2023).

The LFP includes specific eligibility requirements that limit the amount of assistance a producer can receive. Under the Agriculture Improvement Act (the 2018 Farm Bill), LFP benefits are capped at $125,000 per person or legal entity, per year. Additionally, any person or entity with an Adjusted Gross Income (AGI) exceeding $900,000 is ineligible for LFP payments.

To understand the practical implications of these thresholds, in 2023, the program's payment rate covered 60 percent of a national feed cost rate of $58.12 per head per month for adult beef cows, amounting to roughly $34.87 per cow per month ($0.60 \times 58.12 \approx 34.87$). Since LFP provides benefits for up to five months of qualifying drought conditions within a single year, the maximum payment per cow in a given year would be about $174.35 ($34.87 \times 5 \approx 174.35$). Reaching the $125,000 annual payment limit at this rate would require a producer to have around 715 head of cattle ($\$125{,}000 / 174.35 \approx 715$) all qualifying for the full five months of payments. However, such a large herd size is not the norm. National data indicate that fewer than 2 percent of operations maintain more than 500 cows, while the majority hold well under 250 head.

Moreover, even the largest operations tend to fall well below the $900,000 AGI limit. Recent estimates reported by Gillespie et al. (2023) indicate that even cow-calf operations with more than 500 cows have a total household income significantly below this AGI threshold ($238,011 in 2018). Thus, both the payment limitation and the AGI requirement are unlikely to pose constraints for most cattle producers—most will neither approach the $125,000 payment cap nor exceed the $900,000 AGI limit.

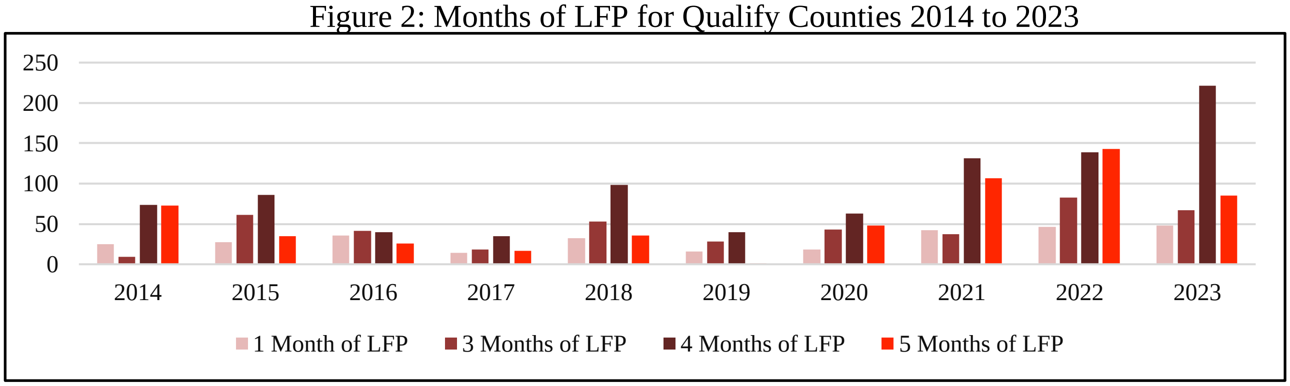
The USDA's Farm Service Agency (FSA) designates multiple pasture types when determining LFP eligibility. Among these, native pasture—non-irrigated rangeland with permanent vegetative cover—serves as the primary measure of LFP eligibility in this analysis. Because it is consistently reported across all years and overlaps heavily with other forage types, using native pasture alone offers a uniform measure of LFP availability for cattle grazing.[4]

Table 3: Distribution of Native Pasture LFP Coverage by County-Year Observations

| LFP Months | Frequency | Percent |
|---|---|---|
| 0 | 7,238 | 76.35% |
| 1 | 304 | 3.21% |
| 3 | 440 | 4.64% |
| 4 | 927 | 9.78% |
| 5 | 571 | 6.02% |
| Total | 9,480 | 100.00% |

In total, there are 9,480 county-year observations from 2014–2023. 76 percent of county-years trigger no LFP in a typical season (LFP=0), while the remainder receive at least 1 month. On average, counties register 0.86 months; the maximum 5-month coverage occurs in about 6 percent of observations. Over time, the fraction of counties with any LFP rose from 19 percent in 2014 to 44 percent in 2023, reflecting more frequent or severe droughts in certain regions.

Figure 2: Months of LFP for Qualify Counties 2014 to 2023




[4] The USDA's FSA publishes annual county-level data on up to 13 distinct pasture types when determining LFP eligibility (Hrozencik et al. 2024). Among them, native pasture**,** full-season improved pasture**,** and warm-season improved pasture collectively accounted for over 94% of total LFP payments in 2019–2022. Each category can differ in its normal grazing window and drought triggers, and some states further distinguish warm- vs. cool-season forages. However, native pasture (defined as non-irrigated rangeland with permanent vegetative cover) is the only type reported every year between 2014 and 2023. Relying on native pasture alone provides a consistent across-year measure of LFP eligibility—particularly as counties that trigger LFP for improved pasture qualify for native pasture 95% of the time. Because native pasture is both ubiquitous in major cattle regions and stably reported over time, using it as the singular pasture type captures the vast majority of LFP activity and avoids data gaps that arise for improved pastures.

### 3.3 The U.S. Drought Monitor Data (USDM)

In contrast to basic weather data, the USDM's multi-variable drought designation provides a comprehensive tool for capturing both the intensity and duration of droughts that directly affect cattle productivity. USDM is produced weekly by the USDA, the National Oceanic and Atmospheric Administration (NOAA), and the National Drought Mitigation Center (NDMC), integrating a wide range of indicators: soil moisture percentile values, daily streamflow percentiles, percentage of average precipitation, standardized precipitation indices (SPI), and remotely sensed measures of vegetation health (USDM, 2024). Expert input from regional and state climatologists, agricultural and water resource managers, and National Weather Service field offices further refines these classifications, ensuring that the maps reflect actual drought conditions and their local impacts.

Based on these combined measures, the USDM categorizes drought severity into five levels: "abnormally dry" (D0), "moderate drought" (D1), "severe drought" (D2), "extreme drought" (D3), and "exceptional drought" (D4).

Table 4: Categories of Drought Intensity Used by the U.S. Drought Monitor

| Categories | Drought Intensity Level | Percentile[5] |
|---|---|---|
| D0 | Abnormally Dry | 20 to ≤ 30 |
| D1 | Drought, moderate | 10 to ≤ 20 |
| D2 | Drought, severe | 5 to ≤ 10 |
| D3 | Drought, extreme | 2 to ≤ 5 |
| D4 | Drought, exceptional | ≤ 2 |

Source: USDM, Drought Classification Page

3.1.1 Weekly Drought Classification

Because a single county-week may span multiple USDM drought categories (e.g., part D1, part D2), I use two distinct methods to assign one classification per county-week. The maximum

[5] The U.S. Drought Monitor's classification system uses percentiles to compare current climatic conditions against a long-term historical record. For example, if current measurements fall below the 10th percentile, this indicates that only 10% of historical observations were drier suggesting unusually dry conditions. Conversely, higher percentiles indicate conditions that are more typical to historical variability. This percentile-based approach provides an objective framework for assessing and communicating drought severity.

classification method flags the county-week by its highest severity category observed (e.g., D3 if any portion of the county is in D3 or worse). By contrast, the dominant classification method picks whichever category covers the largest share of the county (e.g., D1 if 60 percent of the area is D1, and 40 percent is D2). In practice, about 70 percent of county-weeks exhibit exactly one category anyway, so multi-category overlaps arise only in the remaining 30 percent of weeks (e.g., 24 percent have exactly two categories, and around 5 percent have three or more). Hence, either approach yields the same classification for most observations. As Table 5 shows, the mean number of weeks per year in each drought category is somewhat higher under the maximum method.

Table 5: Comparison of "Max" vs. "Dominant" Drought Classification Methods

| | Mean Weeks D0 | Mean Weeks D1 | Mean Weeks D2 | Mean Weeks D3 | Mean Weeks D4 |
|---|---|---|---|---|---|
| Max | 9.54 | 6.70 | 4.53 | 2.81 | 1.21 |
| Dom | 8.66 | 5.82 | 3.71 | 1.99 | 0.72 |

For my main analysis, I adopt the max classification as the primary measure: it captures the most severe drought conditions present in a county at a given time. Because LFP and other drought responses often hinge on the worst category, using the max approach helps align with how producers might perceive risk. Nonetheless, in a robustness check, I test if the dominant classification yields a different result. This test is important given that, for D3 and D4 drought, the mean dominant classification is 29.2% and 40.5% lower mean maximum classification.

Using the maximum definition, Table 6 displays summary statistics for the yearly count of weeks each county spends in each drought category. It reports the mean, standard deviation, and selected percentiles—highlighting that lower-severity categories (D0–D2) are more common, while D3 and D4 droughts are relatively rare.

Table 6: Summary Statistics for Weeks of Drought at Each Duration

| Variable | Obs | Mean | Std. Dev. | % = 0 | Median | 75% | Max |
|---|---|---|---|---|---|---|---|
| Weeks in D0 | 22,752 | 9.544 | 7.790 | 13.3% | 8 | 14 | 52 |
| Weeks in D1 | 22,752 | 6.698 | 7.678 | 31.4% | 4 | 11 | 52 |
| Weeks in D2 | 22,752 | 4.530 | 7.576 | 54.8% | 0 | 7 | 52 |
| Weeks in D3 | 22,752 | 2.808 | 6.897 | 75.7% | 0 | 0 | 53 |
| Weeks in D4 | 22,752 | 1.212 | 5.216 | 91.0% | 0 | 0 | 53 |

Reflecting the same pattern, Figure 3 plots the distribution of county-year observations specifically for D3 and D4 durations. Most counties spend zero weeks in these high-severity classifications in a given year, though a smaller fraction experiences multiple weeks at that level.

Figure 3: Number of County-Year Observations by Duration of D3 and D4 Drought

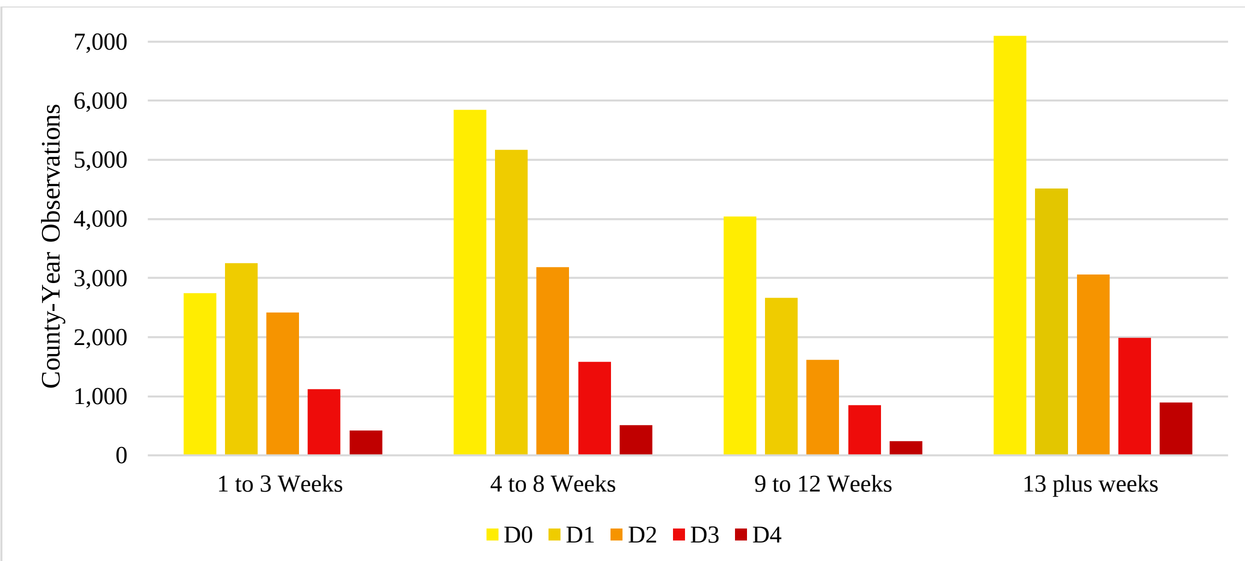



Table 7 shows how often counties encounter at least one or four consecutive weeks of D2–D4 drought. While these thresholds resemble those used by LFP, Table 7 includes all years (even before LFP) and does not account for local grazing windows. Thus, it provides only a broad snapshot of dryness severity—but it does inform our nonlinear approach to higher-severity drought (Section 4.2), particularly given how sparse the data become at the most severe, longer-duration levels.

Table 7: Incidence of High-Severity Drought (D3–D4)

| Drought | % County-Years with ≥1 week | % County-Years with ≥4 weeks | % Counties Never Experiencing This Severity |
|---|---|---|---|
| D3 | 24.3% | 19.4% | 0.2% |
| D4 | 9.0% | 7.2% | 30% |

3.1.2 Consecutive Drought Classification

To measure multi-week drought severity, I track each county's longest uninterrupted run of D0–D4 drought within a calendar year. Specifically, I count consecutive weekly classifications at or above each threshold (e.g., D2+ includes D2, D3, or D4) until the drought designation breaks. For each county–year, the maximum length is capped at 52 weeks to match the annual nature of the herd inventory data; if a drought spills into the next calendar year, it is split between the two years. This framework aligns with the annual structure of both cattle-inventory records and LFP reporting. These consecutive weeks of drought show similar patterns to the cumulative weeks of drought generally peak in well-known dry periods (e.g., 2011–2012, 2021–2022) and remain low in milder years.

**3.4 Controls**

County-level irrigation data are derived from the five-year U.S. Census of Agriculture, carrying over that value in between census years. Only 705 out of 984 counties had complete irrigation data. County-level unemployment rates, sourced from the USDA's Economic Research Service, serve as a proxy for local economic conditions that may influence cattle management decisions.

**3.5 Data Limitations**

A primary limitation of this analysis stems from the absence of USDA administrative data on county-specific grazing periods, which determine whether a drought overlaps with a county's eligible grazing window for LFP. In contrast to studies such as Hrozencik et al. (2024), which incorporate these windows to more precisely model payment eligibility, this paper relies solely on drought severity classifications from the U.S. Drought Monitor (USDM) to construct eligibility triggers.

This constraint can create discrepancies between modeled eligibility and actual payments. For instance, the model identifies a subset of county years with no qualifying drought, despite those observations receiving LFP payments. Such mismatches likely reflect drought episodes that coincide with grazing windows but fall outside the USDM-based triggers. To preserve consistency, I retain all observations rather than exclude mismatched cases—especially given that grazing window data are unavailable for the entire period prior to 2014.

Table 8. Observed Payment Outcomes by Modeled Drought Trigger

| Drought Trigger | Expected LFP Payment Months | Obs. | No Payment (%) | Exact Payment (%) | Other Payment (%) |
|---|---|---|---|---|---|
| Payment Flag 1 | 1 | 465 | 43.01% | 54.62% | 2.37% |
| Payment Flag 3 | 3 | 489 | 31.08% | 60.94% | 7.98% |
| Payment Flag 4 | 4 | 1,133 | 11.47% | 75.11% | 13.42% |
| Payment Flag 5 | 5 | 622 | 2.09% | 87.30% | 10.61% |

To gauge how well the USDM-based triggers align with actual LFP payments, I compare predicted coverage to observed payments (Table 8). Longer-duration droughts generally match actual coverage more closely, whereas shorter-duration triggers often fail to align. This disparity likely arises because LFP also hinges on local grazing windows, and briefer spells of drought—even if they meet the severity threshold—may occur outside of county grazing periods.

Table 9: County-Year Correspondence Between Dryness Triggers and LFP Payment Receipt

| LFP | Receiving this Tier | Matching Drought Criteria | % Matching | Not Matching | % Not Matching |
|---|---|---|---|---|---|
| 1 Month of Payment | 304 | 289 | 95.07% | 15 | 4.93% |
| 3 Months of Payments | 440 | 425 | 96.59% | 15 | 3.41% |
| 4 Months of Payments | 927 | 902 | 97.30% | 25 | 2.70% |
| 5 Months of Payments | 571 | 543 | 95.10% | 28 | 4.90% |

In addition to verifying how often a given pay flag corresponds to actual coverage, I checked the reverse: for county-years actually receiving a particular payment, how many were flagged for that coverage level in the model at any point in the year. As shown in Table 9, the alignment between actual coverage and the model's pay flags is high across all tiers, ranging from approximately 95% for one-month of LFP up to nearly 97% for 4 months of LFP coverage. Thus, when starting from actual coverage records, most of these county-years align with the triggers defined in the model. Some mismatch still occurs—roughly 3–5% of covered county-years lack the corresponding pay flag. I do not have an explanation for this small mismatch, as it means that several county year observations do not experience the required dryness to qualify for certain LFP payments.

## 4 Methods

Producer responses to drought reflect a mix of biological, economic, and logistical constraints. Herd size decisions are shaped by feed costs, pasture conditions, access to water, and more. As drought intensifies, forage quality declines, hay production falls, and local hay prices rise—raising the effective cost of maintaining cattle. During drought, marginal feed costs rise sharply while forage productivity declines, pushing producers to reduce herd size either through immediate culling or delayed restocking. Breeding cycles, capital constraints, and uncertainty about drought persistence all impose adjustment frictions. As a result, drought effects on inventories may materialize gradually rather than immediately, even under severe conditions.

This dynamic is further complicated by federal disaster assistance. Programs like LFP reduce the marginal cost of maintaining cattle during drought, especially when feed prices spike. However, whether LFP materially alters producer behavior depends on the generosity of coverage. A single month of payment may be insufficient to prevent liquidation in the face of prolonged drought, while multi-month support tied to extreme conditions may allow producers to delay or avoid downsizing altogether. In this way, LFP functions not simply as an income transfer, but as a mechanism that can shift the marginal calculus of herd retention under stress.

In the following sections, this paper presents a series of two-way fixed-effects panel models that capture different dimensions of drought severity and duration, LFP coverage, and herd dynamics. Section 4.1 introduces the baseline specification that distinguishes each drought category (D0–D4) and includes LFP coverage tiers (1, 3, 4, 5) along with interaction terms. Section 4.2 refines the measurement of D3 and D4 droughts by segmenting them into short versus long durations, mirroring LFP's multi-month thresholds. Section 4.3 adopts an alternative measure based on the longest consecutive drought spell, which is particularly relevant for severe (D2) conditions, and Section 4.4 integrates these consecutive and segmented definitions to align more closely with LFP's actual triggers.

**4.1 Baseline Regression**

This baseline specification estimates the effect of drought severity and LFP coverage on county-level cattle inventories. It includes interaction terms to test whether specific tiers of LFP coverage mitigate the effects of the drought severities they are designed to offset. Because herd adjustments typically occur gradually, all time-varying regressors—including drought indicators and LFP coverage—are lagged by one year to capture the delayed response of cattle inventories. Formally:

$$
\begin{aligned}
\ln\left(\mathrm{Cattle}_{i,t}\right) &= \beta_0 + \sum_{k=0}^{4} \beta_k \ \mathrm{D}_{k,i,t-1} + \\
&\gamma_1 \left(\mathrm{LFP1}_{i,t-1}\right) + \gamma_2 \left(\mathrm{LFP3}_{i,t-1}\right) + \gamma_3 \left(\mathrm{LFP4}_{i,t-1}\right) + \gamma_4 \left(\mathrm{LFP5}_{i,t-1}\right) + \\
&\delta_1 \left[\mathrm{D2}_{i,t-1} \times (\mathrm{LFP1})_{i,t-1}\right] + \delta_2 \left[\mathrm{D3}_{i,t-1} \times (\mathrm{LFP3})_{i,t-1}\right] + \delta_3 \left[\mathrm{D3}_{i,t-1} \times (\mathrm{LFP4})_{i,t-1}\right] + \\
&\delta_4 \left[\mathrm{D4}_{i,t-1} \times (\mathrm{LFP4})_{i,t-1}\right] + \delta_5 \left[\mathrm{D4}_{i,t-1} \times (\mathrm{LFP5})_{i,t-1}\right] \\
&\phi_1 \,\mathrm{Irrigation}_{i,t-1} + \phi_2 \ \zeta_{i,t-1} + \alpha_i + \xi_t + \epsilon_{it}
\end{aligned}
\tag{4.1}
$$

Where $\mathrm{Cattle}_{i,t}$ is the beef cattle population in county *i* at year *t* ; $\mathrm{D}_{k,i,t-1}$ are lagged indicators for USDM drought severity levels $k \in \{0, \ldots, 4\}$ (with D0 = abnormally dry, D4 = exceptional drought); $\mathrm{LFP}j_{\mathrm{i,t-1}}$ denotes last year's LFP coverage tier $j \in \{1, 3, 4, 5\}$; the interaction terms measure how specific coverage levels modify drought impacts. $\mathrm{Irrigation}_{i,t-1}$ and $\zeta_{i,t-1}$ are county level controls for irrigation and a local economic indicator; $\alpha_i$ and $\xi_t$ represent county and year fixed effects, respectively; $\epsilon_{it}$ is the error term. Standard errors are clustered at the county level.

4.1.1 Independent Variable

The dependent variable in this analysis is the natural log of beef cattle populations county $i$ at year *t*. Taking the natural log helps stabilize variance across observations and allows the coefficients to be interpreted as percentage changes. Although farm-level data could offer a more granular perspective, the available data are aggregated at the county level.

4.1.2 USDM Drought Designation

In this specification, the vector of coefficients ($\beta_1, \ldots, \beta_4$) captures how an additional week of each USDM drought severity category (D0 through D4) affects $ln(\text{Cattle}_{i,t})$. We omit an indicator for "no drought," so each $\beta_k$ is interpreted relative to being completely drought-free, following the framework of Kuwayama et al. (2018). We lag these drought variables because herd adjustments typically unfold gradually. Ranchers respond not just to current dryness but to persistent or historical conditions, which may affect breeding, culling, or restocking decisions into the following year (UNL–NDMC 2023). These drought variables are first included without interactions (i.e., no coverage terms), they represent the direct effect of dryness on counties that did not receive LFP payments—either before the program's expansion in 2014 or droughts occurred outside of county-specific grazing criteria.

4.1.3 LFP Payments

$\text{LFP}j_{\text{i,t-1}}$ represent whether county *I* received 1, 3, 4, or 5 months coverage in year *t* -l, without experiencing the corresponding drought conditions. I lagged these payment variables because the deadline for applications to LFP are typically March 1 of the year following the drought conditions—meaning a county's coverage for dryness in year $t - 1$ may not be recorded or finalized until the next calendar year. Second, cattle herd decisions often adjust gradually: ranchers may fully realize or utilize coverage proceeds (e.g., to offset feed costs) over the subsequent year, rather than immediately. In theory, if policy triggers operated with perfect precision (e.g., full alignment between drought severity and grazing-period eligibility), these coverage tiers would be redundant. For example, any county receiving 5 months of LFP payments should also meet the D4 drought criteria. Coverage, however, is not strictly deterministic as discussed in Section 3.5. Several counties that received payment did not have the corresponding drought qualifications. Consequently, we include these LFP coverage tiers explicitly.

#### 4.1.4 Interaction Terms of Drought Designations and LFP Payments

Interaction terms for drought severity levels (D2, D3, D4) with their corresponding LFP coverage tiers allow for an analysis of how effective each payment tier is in mitigating drought effects. For instance, severe drought (D2) is interacted with 1-month coverage $\mathrm{D2}_{i,t-1} \times (\mathrm{LFP1})_{i,t-1}$ because at least eight consecutive weeks of D2 alone qualify for a single-month payment, but never for the 3, 4, or 5-month tiers. This approach reflects the policy reality that multi-month benefits require specific levels of severity.

Each interaction term isolates how much a given coverage tier offsets the impact of the drought severity it was designed to address. The standalone drought coefficients $\mathrm{D}_{4,i,t-1}$ represent the impact of dryness absent coverage, and the interaction $\mathrm{D4}_{i,t-1} \times (\mathrm{LFP5})_{i,t-1}$ indicates how 5 months of assistance modifies that same dryness. A significant, positive interaction term indicates that LFP payments alleviate the detrimental impact of drought on cattle inventories. This design extends prior work

(Hrozencik et al., 2024) that focused only on a 1-month threshold. In doing so, it enables an analysis across the full spectrum of LFP durations (1 to 5 months), exploiting variation both before and after the program's expansion.

### 4.1.5 Controls

I also include the terms $\text{Irrigation}_{i,t-1}$ and $\zeta_{i,t-1}$ to capture, respectively, the county's irrigation status and local economic conditions as measured by the unemployment rate. Although some studies find irrigation can buffer yield losses in crops (Kuwayama et al., 2018), its effectiveness in livestock settings remains inconclusive (Rodziewicz et al., 2023). As a result, I treat irrigation as a baseline characteristic and remove it in robustness checks. Meanwhile, I use the unemployment rate $\zeta_{i,t-1}$ to approximate broader local economic health, which might affect smaller producers in particular. High unemployment could reflect reduced regional demand for beef, diminished labor availability, or fiscal constraints on producers' capacity to cope with drought shocks. Thus, including $\zeta_{i,t-1}$ helps separate changes in herd size driven by county-specific economic downturns from those driven specifically by dryness or policy interventions. Other potential controls, as discussed in the literature review, were omitted to avoid mediator bias and to preserve consistency with earlier studies.

### 4.1.6 Fixed Effects and Error Term

In my model, I include county-fixed effects $\alpha_i$ to capture each county's, time-invariant characteristics—such as soil, ranching practices, or geographic features—and thereby isolate how drought and federal assistance affect changes within counties over time. Additionally, as I use year-fixed effects $\xi_t$, like Rodziewicz et al. (2023), rather than state-specific linear trends as in Kuwayama et al. (2018), for two principal reasons. First, cattle herds often exhibit nonlinear or cyclical fluctuations (e.g., expansion-contraction phases, feed price shocks, changes in beef demand) that a single linear slope per state would not fully capture. Including year fixed effects absorbs national-level shocks and macro trends that might otherwise bias estimates of drought effects. Second, the panel spans a fairly long period (2000–2023) with hundreds of counties, so year dummies can flexibly account for common shocks (e.g., evolving beef demand) without forcing a uniform linear trajectory.

To address potential issues with heteroscedasticity and serial correlation in the error terms, I cluster standard errors at the county level. Because the panel structure includes multiple observations for each county over time, the residuals are unlikely to be independent and identically distributed (i.i.d.). Clustering corrects for the possibility that unobserved shocks or patterns affecting cattle populations are correlated within counties across years.

#### 4.1.7 Dynamic Adjustment: Lagged Cattle Inventories

To better capture the inherent inertia of herd decisions, I extend the model to include a lagged dependent variable (LDV). This specification allows for more gradual herd adjustments, which better reflect producers' real-world constraints—such as breeding cycles, feed availability, and evolving market signals. U.S. Department of Agriculture, Economic Research Service (2025) estimate that the cattle cycles of decline and growth last 8-12 years. While many earlier studies have examined drought impacts using only contemporaneous or lagged dryness measures (Rodziewicz et al., 2023), they do not integrate a fully dynamic approach. This framework thus addresses last year's herd size influences over this year's inventories, in addition to any effect of drought or LFP coverage from the previous year. Because the LDV inevitably retains unit-specific heterogeneity and thus remains correlated with the fixed effect—leading to a biased LDV coefficient—it makes the drought and payment coefficient less biased.

4.1.8 Weighted Estimation: Population-Adjusted Effects

Finally, I estimate a version of the model weighted by each county's previous-year cattle population. From a policy perspective, counties with larger herds are more consequential for aggregate beef supply and prices; thus, weighting observations by how many head of cattle they maintained last year effectively prioritizes the regions where drought and federal assistance may have the greatest impact on national beef markets. I employ the lagged (rather than current) herd size to avoid weighting by my dependent variable in the same period, which could artificially amplify or dampen certain observations based on the outcome I seek to explain. Through this weighting, I preserve the logic that bigger cattle counties (as of last year) should receive proportionally more influence in the regression, while still preventing the potentially circular practice of weighting each county-year by its own current inventory.

## 4.2 Segmented Model: Severity Thresholds Aligned with LFP Tiers

To refine the measurement of drought intensity, I disaggregate D3 and D4 into segmented indicators that distinguish between short and long durations. This segmentation reflects that the economic and operational consequences of drought may not be merely linear; a brief spell of severe drought may allow producers to absorb losses through modest adjustments. As dryness persists, pastures fail to recover, water sources remain depleted, and cumulative feed expenses mount, which could drive heavier culling or herd liquidation (USGCRP, 2018). To capture these nonlinear effects, I disaggregate D3 and D4 exposures into short and long durations, thereby allowing the model to distinguish between relatively moderate impacts from isolated severe events and substantially larger damages from extended episodes. Rather than using total weekly counts, I define "Short Duration D3/D4" as less than 4 weeks of drought and "Long Duration D3/D4" as 4 or more weeks of drought, consistent with LFP eligibility criteria. Thus, if a county experiences 10 consecutive weeks of D3, it has 3 weeks of short-duration D3 and 7 weeks of long-duration D3, summing to 10. I apply this strategy only to D3 and D4 because they are the only drought levels for which LFP increases coverage based on longer durations. By contrast, D2 drought uses one fixed eligibility threshold, meaning D2 drought can either qualify a county for 0 or 1 month of payment.

Limiting the bins to two per severity level helps preserve statistical power and avoid overfitting, especially for exceptional (D4) droughts, which are relatively rare. This approach also mirrors LFP's multi-week structure, thereby providing a more policy-aligned framework for testing whether herds respond differently to brief versus extended high-severity drought.

$$
\begin{aligned}
&\ln\left(\text{Cattle}_{i,t}\right) = \beta_0 + \beta_1 \text{D0}_{i,t-1} + \beta_2 \text{D1}_{i,t-1} + \beta_3 \text{D2}_{i,t-1} \\
&+\beta_4 \text{Short Duration D3}_{i,t-1} + \beta_5 \text{Long Duration D3}_{i,t-1} \\
&+\beta_6 \text{Short Duration D4}_{i,t-1} + \beta_7 \text{Long Duration D4}_{i,t-1} \\
&\gamma_1 \left(\text{LFP1}_{i,t-1}\right) + \gamma_2 \left(\text{LFP3}_{i,t-1}\right) + \gamma_3 \left(\text{LFP4}_{i,t-1}\right) + \gamma_4 \left(\text{LFP5}_{i,t-1}\right) + \\
&\delta_1 \left[\text{D2}_{i,t-1} \times (\text{LFP1})_{i,t-1}\right] + \\
&\delta_2 \left[\text{Short Duration D3}_{i,t-1} \times (\text{LFP3})_{i,t-1}\right] + \delta_3 \left[\text{Long Duration D3}_{i,t-1} \times (\text{LFP4})_{i,t-1}\right] + \\
&\delta_4 \left[\text{Short Duration D4}_{i,t-1} \times (\text{LFP4})_{i,t-1}\right] + \delta_5 \left[\text{Long Duration D4}_{i,t-1} \times (\text{LFP5})_{i,t-1}\right] + \\
&\phi_1 \text{Irrigation}_{i,t-1} + \phi_2\, \zeta_{i,t-1} + \alpha_i + \xi_t + \epsilon_{it}
\end{aligned}
\tag{4.2}
$$

Compared to the baseline model, this specification captures the potentially nonlinear relationship between drought duration and herd outcomes: a county facing only a few weeks of D3 might behave differently than one facing a longer spell of the same severity. All LFP tiers and controls remain defined as in Equation (4.1), preserving consistency across specifications.

### 4.3 Consecutive Weeks Model

This specification captures drought severity by measuring the longest uninterrupted streak of D*k* or worse weeks in each year. Unlike the total weeks approach, this model emphasizes sustained dryness.

Consecutive weeks may impose escalating feed and hay costs, forcing culling decisions, and depleting local forage resources, so focusing on consecutive weeks emphasizes these effects of herd management decisions (USGCRP, 2018). This approach may be particularly relevant D2, where the LFP requires eight consecutive weeks before coverage is triggered, though the framework also captures the persistence of D3 and D4. I replace total weekly drought counts with Consecutive Weeks of D*k*+ (D*k* or worse) defined for each category $k \in \{0, \ldots, 4\}$ :

$$
\begin{aligned}
&\ln\left(\text{Cattle}_{i,t}\right) = \beta_0 + \sum_{k=0}^{4} \beta_k \text{ Consecutive Weeks of D}k{+}_{i,t-1} + \\
&\gamma_1\left(\text{LFP1}_{i,t-1}\right) + \gamma_2\left(\text{LFP3}_{i,t-1}\right) + \gamma_3\left(\text{LFP4}_{i,t-1}\right) + \gamma_4\left(\text{LFP5}_{i,t-1}\right) + \\
&\delta_1\left[\text{Consecutive Weeks of D2+}_{i,t-1} \times (\text{LFP1})_{i,t-1}\right] + \\
&\delta_2\left[\text{Consecutive Weeks of D3+}_{i,t-1} \times (\text{LFP3})_{i,t-1}\right] + \\
&\delta_3\left[\text{Consecutive Weeks of D3}_{i,t-1} \times (\text{LFP4})_{i,t-1}\right] + \\
&\delta_4\left[\text{Consecutive Weeks of D4}_{i,t-1} \times (\text{LFP4})_{i,t-1}\right] + \\
&\delta_5\left[\text{Consecutive Weeks of D4}_{i,t-1} \times (\text{LFP5})_{i,t-1}\right] + \\
&\phi_1 \text{ Irrigation}_{i,t-1} + \phi_2\, \zeta_{i,t-1} + \alpha_i + \xi_t + \epsilon_{it}
\end{aligned}
\tag{4.3}
$$

The model retains all LFP coverage tiers, interaction terms, and control variables as specified in the baseline (Eq. 4.1). This consistency allows a direct comparison with prior specifications. One nuance is that consecutive weeks of D3+ may include stretches of D4, since higher-intensity droughts also meet lower-threshold definitions. As a result, the coefficients now reflect not just intensity, but the persistence of that intensity.

### 4.4 LFP-Aligned Model

This final specification most closely reflects the actual design of LFP. It integrates two forms of drought measurement: (1) consecutive weeks of D0, D1, and D2, and (2) segmented durations of D3 and

D4. This combination allows me to align the drought variables precisely with LFP's multi-tier eligibility framework:

$$
\begin{aligned}
&\ln\left(\text{Cattle}_{i,t}\right) = \beta_0 + \ \beta_1 \text{Consecutive Weeks of } \text{D0+}_{i,t-1} \\
&+\beta_2 \text{Consecutive Weeks of } \text{D1+}_{i,t-1} + \ \beta_3 \text{Consecutive Weeks of } \text{D2+}_{i,t-1} \\
&+\beta_4 \text{Short Duration D3}_{i,t-1} + \beta_5 \text{Long Duration D3}_{i,t-1} \\
&+\beta_6 \text{Short Duration D4}_{i,t-1} + \beta_7 \text{Long Duration D4}_{i,t-1} \\
&\gamma_1 \left(\text{LFP1}_{i,t-1}\right) + \gamma_2 \left(\text{LFP3}_{i,t-1}\right) + \gamma_3 \left(\text{LFP4}_{i,t-1}\right) + \gamma_4 \left(\text{LFP5}_{i,t-1}\right) \ + \\
&\delta_1 \left[\text{Consecutive Weeks of } \text{D2+}_{i,t-1} \times (\text{LFP1})_{i,t-1}\right] + \\
&\delta_2 \left[\text{Short Duration D3}_{i,t-1} \times (\text{LFP3})_{i,t-1}\right] + \delta_3 \left[\text{Long Duration D3}_{i,t-1} \times (\text{LFP4})_{i,t-1}\right] + \\
&\delta_4 \left[\text{Short Duration D4}_{i,t-1} \times (\text{LFP4})_{i,t-1}\right] + \delta_5 \left[\text{Long Duration D4}_{i,t-1} \times (\text{LFP5})_{i,t-1}\right] + \\
&\ \phi_1 \text{ Irrigation}_{i,t-1} \ + \ \phi_2 \ \zeta_{i,t-1} + \alpha_i + \xi_t + \epsilon_{it}
\end{aligned}
\tag{4.4}
$$

Consecutive D2 weeks are directly tied to the 1-month coverage threshold, while short and long durations of D3 and D4 proxy for eligibility for 3–5-month coverage tiers. These definitions provide a policy-grounded segmentation of drought severity and persistence. Compared to earlier models, this framework maps more directly onto the program's operational rules. Although some approximations remain (e.g., my D2 cutoff may not exactly match the 8-week rule), this specification is designed to evaluate how well the LFP mitigates the kinds of droughts it was intended to cover.

By nesting all relevant thresholds within a single model, I create the most direct empirical test of whether LFP offsets the effects of eligible drought episodes on cattle inventories. LFP coverage tiers, interactions, and controls are retained as previously specified. This structure provides the clearest lens into whether federal assistance achieves its stated goal: helping producers sustain herd sizes in the face of sustained or severe dryness.

# 5 Results

This section presents results from four empirical specifications designed to test how cattle inventories respond to drought exposure and whether those responses align with the structure of the LFP. Each model builds on the baseline specification by modifying the treatment of drought severity, duration, or persistence, while maintaining a fixed-effects regression framework with controls for irrigation, unemployment, year, and county fixed effects.

Equation 4.1 serves as the baseline and models drought linearly using weekly counts for each severity level (D0–D4), alongside LFP eligibility tiers and their interactions. Equation 4.2 introduces a segmented strategy that segments D3 and D4 droughts into short (1–3 weeks) and long (4+ weeks) durations, allowing for nonlinear effects. Equation 4.3 re-specifies drought exposure in terms of the longest uninterrupted spell of each severity level in a given year—capturing persistence rather than cumulative exposure. Finally, Equation 4.4 combines both segmented and persistence to mimic LFP's eligibility logic more directly. Across specifications, I evaluate how cattle inventories respond to drought conditions and whether federal coverage appears to mitigate those effects. I report results for each model in turn and then assess their comparative strengths for evaluating the effectiveness of LFP coverage.

## 5.1 Equation 4.1 Baseline Specifications

Table 10 presents four model variations. Columns (1) and (2) exclude or include an LDV, while columns (3) and (4) repeat these specifications with observations weighted by last year's herd size. These variations illustrate how incorporating lagged outcomes and weighting affect the estimated impact of drought and LFP coverage on herd sizes.

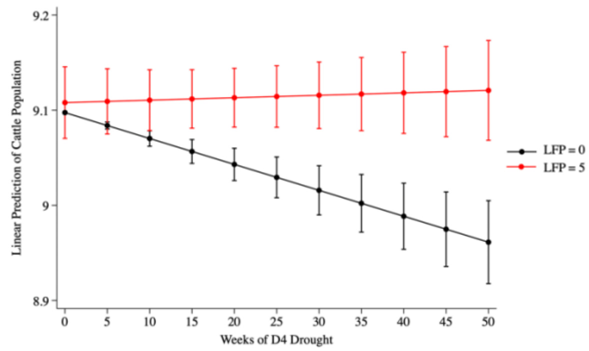
Table 10: Equation 4.1 Regression Results

| | (1) Base | (2) + LDV | (3) + Weights | (4) + LDV & Weights |
|---|---|---|---|---|
| L1: ln(Cattle) | | 0.78267*** | | 0.76922*** |
| | | (0.00838) | | (0.00809) |
| *Drought Conditions* | | | | |
| L1: Weeks in D0 | 0.00015 | 0.00023* | -0.00019 | -0.00011 |
| | (0.00022) | (.00012) | (0.00018) | (0.00011) |
| L1: Weeks in D1 | -0.00032 | -0.00006 | -0.00036 | -0.00016 |
| | (0.00022) | (0.00012) | (0.00025) | (0.00010) |
| L1: Weeks in D2 | -0.00001 | -0.00016 | -0.00057** | -0.00017 |
| | (0.00025) | (0.00016) | (0.00025) | (0.00013) |
| L1: Weeks in D3 | -0.00109*** | -0.00054*** | -0.00118*** | -0.00048*** |
| | (0.00030) | (0.00018) | (0.00029) | (0.00017) |
| L1: Weeks in D4 | -0.00273*** | -0.00100*** | -0.00208*** | -0.00102*** |
| | (0.00046) | (0.00025) | (0.00038) | (0.00022) |
| *LFP Payments* | | | | |
| L1: 1 Month of LFP | -0.00899 | -0.01786* | 0.00084 | -0.01509 |
| | (0.02506) | (0.01071) | (0.01774) | (0.01106) |
| L1: 3 Months of LFP | -0.00299 | -0.00103 | 0.00958 | -0.00223 |
| | (0.01364) | (0.00738) | (0.01234) | (0.00554) |
| L1: 4 Months of LFP | -0.01555 | -0.01719** | -0.02603* | -0.01237* |
| | (0.01362) | (0.00711) | (0.01365) | (0.00633) |
| L1: 5 Months of LFP | 0.01049 | -0.00852 | 0.03056* | -0.00981 |
| | (0.01957) | (0.00904) | (0.01632) | (0.00867) |
| *Interactions* | | | | |
| L1: D2 x 1 LFP | 0.00053 | 0.00082* | 0.00092 | 0.00067 |
| | (0.00108) | (0.00045) | (0.00080) | (0.00042) |
| L1: D3 x 3 LFP | -0.00053 | 0.00013 | -0.00043 | 0.00039 |
| | (0.00188) | (0.00090) | (0.00151) | (0.00070) |
| L1: D3 x 4 LFP | 0.00195** | 0.00157*** | 0.00232*** | 0.00118*** |
| | (0.00078) | (0.00037) | (0.00075) | (0.00031) |
| L1: D4 x 4 LFP | 0.00009 | 0.00108 | -0.00019 | -0.00004 |
| | (0.00221) | (0.00080) | (0.00166) | (0.00087) |
| L1: D4 x 5 LFP | 0.00298*** | 0.00187*** | 0.00140** | 0.00212*** |
| | (0.00083) | (0.00046) | (0.00064) | (0.00050) |
| *Controls* | | | | |
| L1: Unemployment | 0.00059 | -0.00043 | 0.00062 | -0.00031 |
| | (0.00244) | (0.00099) | (0.00190) | (0.00085) |
| L1: Irrigation | -0.00123** | -0.00027* | -0.00080* | -0.00041*** |
| | (0.00055) | (0.00015) | (0.00048) | (0.00014) |
| Year Fixed Effects | Yes | Yes | Yes | Yes |
| County Fixed Effects | Yes | Yes | Yes | Yes |
| Observations | 16,215 | 16,215 | 16,215 | 16,215 |
| Counties | 705 | 705 | 705 | 705 |
| Constant | 9.19361*** | 1.99284*** | 9.95401*** | 2.30102*** |
| | (.0185419) | (.0768378) | (0.0157874) | (0.0795835) |
| $R^2$ (Within) | .0965 | .6505 | .1036 | .6383 |
| $R^2$ (Between) | .0210 | .9997 | .0054 | .9997 |
| $R^2$ (Overall) | .0099 | .9882 | .0050 | .9881 |
| F Statistic | 48.40 | 531.18 | 70.13 | 665.92 |

Notes: Standard errors clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

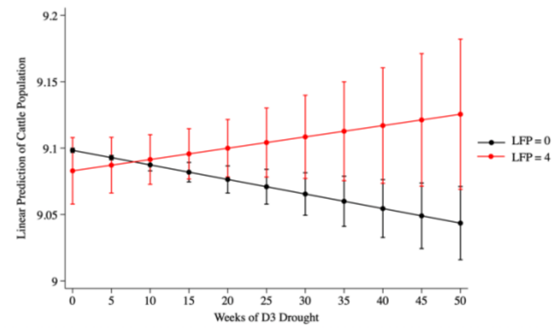
Figure 4: Predictive Margins for Baseline Model Interactions with LFP Coverage

A: Weeks of D4 x 5 LFP Months



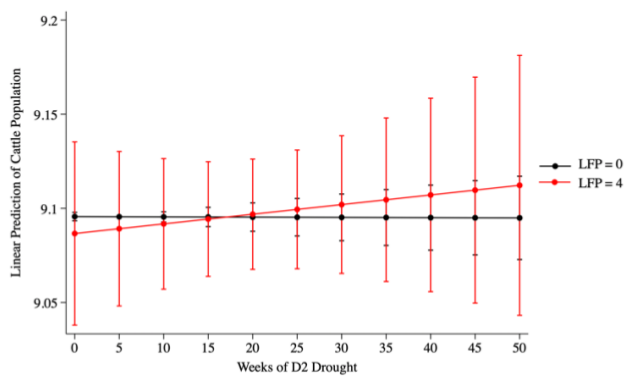

*Predicted log cattle inventories by weeks of D4 drought, with and without 5 month LFP assistance. The figure shows a clear divergence: herd sizes decline steadily without coverage, while 5 month LFP mitigates inventory losses across the entire drought duration range. Vertical bars represent 95% confidence intervals.*

B: Weeks of D3 x 4 LFP Months




*Estimated cattle population trajectories during D3 drought, conditional on receiving 4 month LFP coverage. While herds decline under prolonged D3 conditions without coverage, LFP appears to stabilize or increase inventories among covered counties. Vertical bars represent 95% confidence intervals.*

C: Weeks of D2 x 1 LFP Months




*Estimated marginal effects of 1 month LFP coverage during moderate (D2) drought, which are insignificant. The figure suggests minimal separation in herd response between covered and uncovered counties, consistent with weaker or non-significant mitigation at the lowest tier of coverage. Vertical bars represent 95% confidence intervals.*

In the simplest specification (column 1), exceptional drought (D4) shows the steepest negative effect on county-level cattle inventories (-0.273 percent per week), followed by extreme drought (D3), (-

0.11 percent). To quantifying this, an average county with around 12,900 cattle facing 10 weeks of D4 would see about a 2.73 percent overall herd reduction—roughly 350 head. The coefficients for severe (D2), moderate (D1), and abnormally dry (D0) conditions are smaller and statistically insignificant, indicating that only the most severe droughts significantly reduce herd size.

Although the lagged dependent variable (LDV) is biased, it emerges as highly significant and substantially boosts the model's $R^2$. This indicates that part of drought's impact is captured by prior-year herd inventories. Because herd decisions are sticky, drought effects accumulate over multiple years rather than forcing a one-time cull. Table A6 (Appendix) introduces more lagged drought variables, showing that dryness from up to two years prior still influences herd sizes. Together, these results also confirm that LFP payments—particularly the 5 month tier—work over an extended horizon to partially offset cumulative drought impacts.

When weights are applied (column 3), D2 becomes weakly significant, which suggests it is more impactful in larger, high-production counties. However, once the LDV is introduced, that weak significance fades, reinforcing that only severe dryness categories (D3 and D4) impose the greatest liquidation pressure on cow-calf producers.

The standalone coefficients for LFP coverage tiers are mixed, likely reflecting an imperfect mapping between USDM drought ratings and actual LFP disbursements. As noted in Section 3.5, payment eligibility does not always have a corresponding dryness indicator, but this is only true for less than 5% of total payments. Accordingly, I refrain from interpreting these coefficients further, as they are likely driven by measurement mismatch rather than underlying economic mechanisms.

However, the interaction terms between drought and LFP coverage are more informative. For instance, in counties experiencing D3 drought, 4 month LFP assistance is associated with a 0.195 percent higher inventory, while for D4 drought, 5 months of LFP payments offset herd losses by approximately 0.298 percent per week. Figure 4 illustrates these divergent herd trajectories, highlighting the mitigating role of appropriately aligned LFP coverage.

These findings echo Rodziewicz et al. (2023), who likewise show that severe drought intensifies livestock losses disproportionately. Meanwhile**,** the lack of strong, consistent effects for 1 month LFP coverage under severe D2 drought aligns with Hrozencik et al. (2024): conditions must be sufficiently severe to provoke large-scale culling before payments can substantially alter herd outcomes. Interestingly, although D2 drought is not significant, 1 month of LFP coverage in column (2) is borderline significant.

While Rodziewicz et al. (2023) find significant effects for aggregated D0–D2 dryness, separating D0, D1, and D2 here does not consistently yield strong results. Collapsing them occasionally produces significance when weighting is applied, shown in Table A4 (Appendix). Rodziewicz et al. (2023) more aggressively trimmed his data set, focusing on counties with a high threshold of cattle production, which may explain our divergent findings.

Irrigation is consistently negative and is generally significant. One likely explanation for the negative coefficient on irrigation is that, in many areas, producers who have access to irrigation tend to shift their focus from extensive cattle-grazing to irrigated crops that provide higher, more stable returns. In other words, rather than using irrigated water primarily to support forage or pasture for cattle, farmers may opt to grow more profitable row crops or specialty crops once irrigation is in place. This reallocation can reduce overall cattle numbers, even after controlling for drought conditions, because land and water resources end up dedicated to crop production rather than livestock. Over time, such patterns show up as an inverse relationship between irrigation and cattle inventory in the regression results.

Overall, the baseline fixed-effects model confirms that D3 and D4 drought exert the strongest negative effect on herds, while LFP coverage at 4–5 months can partially offset these losses. The results hold under variations with lagged outcomes and weighting, reinforcing that extreme dryness is the key driver of herd liquidation decisions.

### 5.2 Refining Drought Exposure: Nonlinearity, Persistence, and Policy Alignment

The baseline specification assumes that cattle inventories respond linearly to each additional week of drought at a given severity level. Yet producers may be more sensitive to drought thresholds or to the sustained nature of drought episodes, especially when these features correspond to program eligibility rules. To test these hypotheses, I estimate three alternative models that adjust the way drought exposure is captured, while maintaining a consistent two-way fixed-effects regression framework.

Table 11: Comparative Regression Results for Equations 4.2–4.4

| | (1) Equation 4.2 | | (2) Equation 4.3 | | (3) Equation 4.4 |
|---|---|---|---|---|---|
| *Drought Conditions* | | *Drought Conditions* | | *Drought Conditions* | |
| L1: Weeks in D0 | 0.00012 | L1: Max Run D0+ | 0.00020 | L1: Max Run D0+ | 0.00015 |
| | (0.00022) | | (0.00024) | | (0.00024) |
| L1: Weeks in D1 | -0.00037* | L1: Max Run D1+ | -0.00056* | L1: Max Run D1+ | -0.00059* |
| | (0.00022) | | (0.00033) | | (0.00033) |
| L1: Weeks in D2 | -0.00018 | L1: Max Run D2+ | -0.00001 | L1: Max Run D2+ | -0.00011 |
| | (0.00026) | | (0.00037) | | (0.00037) |
| L1: Short D3 | 0.00285 | L1: Max Run D3+ | -0.00090** | L1: Short D3 | 0.00406* |
| | (0.00215) | | (0.00042) | | (0.00216) |
| L1: Long D3 | -0.00159*** | L1: Max Run D4 | -0.00152** | L1: Long D3 | -0.00110** |
| | (0.00038) | | (0.00059) | | (0.00043) |
| L1: Short D4 | -0.00267 | | | L1: Short D4 | -0.00188 |
| | (0.00332) | | | | (0.00335) |
| L1: Long D4 | -0.00289*** | | | L1: Long D4 | -0.00242*** |
| | (0.00061) | | | | (0.00065) |
| *LFP Payments* | | *LFP Payments* | | *LFP Payments* | |
| L1: 1 Month of LFP | -0.00845 | L1: 1 Month of LFP | 0.00224 | L1: 1 Month of LFP | 0.00403 |
| | (0.02513) | | (0.02485) | | (0.02497) |
| L1: 3 Months of LFP | 0.03124 | L1: 3 Months of LFP | -0.00233 | L1: 3 Months of LFP | 0.03119 |
| | (0.02974) | | (0.01342) | | (0.02957) |
| L1: 4 Months of LFP | -0.01307 | L1: 4 Months of LFP | -0.00852 | L1: 4 Months of LFP | -0.01146 |
| | (0.01396) | | (0.01363) | | (0.01406) |
| L1: 5 Months of LFP | 0.01618 | L1: 5 Months of LFP | 0.01437 | L1: 5 Months of LFP | 0.01678 |
| | (0.02050) | | (0.01968) | | (0.02068) |
| *Interactions* | | *Interactions* | | *Interactions* | |
| L1: D2 x 1 LFP | 0.00059 | L1: D2+ x 1 LFP | 0.00017 | L1: D2+ x 1 LFP | 0.00018 |
| | (0.00108) | | (0.00106) | | (0.00106) |
| L1: Short D3 x 3 LFP | -0.01905 | L1: D3+ x 3 LFP | -0.00034 | L1: Short D3 x 3 LFP | -0.01917 |
| | (0.01257) | | (0.00191) | | (0.01252) |
| L1: Long D3 x 4 LFP | 0.00227*** | L1: D3+ x 4 LFP | 0.00198** | L1: Long D3 x 4 LFP | 0.00224*** |
| | (0.00081) | | (0.00084) | | (0.00081) |
| L1: Short D4 x 4 LFP | -0.01186 | L1: D4 x 4 LFP | -0.00298 | L1: Short D4 x 4 LFP | -0.01213 |
| | (0.00759) | | (0.00221) | | (0.00759) |
| L1: Long D4 x 5 LFP | 0.00303*** | L1: D4 x 5 LFP | 0.00294*** | L1: Long D4 x 5 LFP | 0.00298*** |
| | (0.00093) | | (0.00088) | | (0.00093) |
| *Controls* | | *Controls* | | *Controls* | |
| L1: Unemployment | 0.00065 | L1: Unemployment | 0.00071 | L1: Unemployment | 0.00072 |
| | (0.00243) | | (0.00244) | | (0.00244) |
| L1: Irrigation | -0.00123** | L1: Irrigation | -0.00123** | L1: Irrigation | -0.00123** |
| | (0.00055) | | (0.00055) | | (0.00055) |
| Year Fixed Effects | Yes | Year Fixed Effects | Yes | Year Fixed Effects | Yes |
| County Fixed Effects | Yes | County Fixed Effects | Yes | County Fixed Effects | Yes |
| Observations | 16,215 | Observations | 16,215 | Observations | 16,215 |
| Counties | 705 | Counties | 705 | Counties | 705 |
| Constant | 9.19457*** | Constant | 9.19457*** | Constant | 9.19377*** |
| | (0.018478) | | (0.01807) | | (0.01805) |
| $R^2$ (Within) | 0.09680 | $R^2$ (Within) | 0.09660 | $R^2$ (Within) | 0.09710 |
| $R^2$ (Between) | 0.01990 | $R^2$ (Between) | 0.01740 | $R^2$ (Between) | 0.01720 |
| $R^2$ (Overall) | 0.00970 | $R^2$ (Overall) | 0.00910 | $R^2$ (Overall) | 0.00910 |
| F Statistic | 47.42 | F Statistic | 47.71 | F Statistic | 46.81 |

Standard errors clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table 11 compares side-by-side results for Equations 4.2 through 4.4. Column (1) (Equation 4.2) segments D3 and D4 droughts into short (1–3 weeks) versus long (4+ weeks) episodes, allowing for threshold-based jumps in response. Column (2) (Equation 4.3) examines the longest uninterrupted spell of each drought level, testing whether a single sustained run affects herds differently from cumulative weeks. Column (3) (Equation 4.4) uses consecutive weeks for D0–D2 and duration bins for D3 and D4, mirroring LFP's tiered logic. All these models omit the LDV and weights to ensure comparability, since overlapping drought spells across years can complicate the LDV or weighted approaches. As shown in Section 5.1, the main patterns are broadly similar across specifications; the full, detailed estimates with lagged variables and weights are in Tables A1, A2, and A3 (Appendix).

### 5.2.1 Nonlinearity: Equation 4.2

Column (1) segments D3 and D4 droughts into "short" (1–3 weeks over the calendar year) and "long" (4 or more weeks over the year). The estimates show that long-duration D3 drought corresponds to about a 0.159 percent decline in cattle inventories per week, while long-duration D4 drought lowers them by about 0.289 percent per week. Both effects are statistically significant at the 1% level and broadly align with the magnitudes observed in the baseline Equation 4.1.

By contrast, the short-duration categories (1–3 weeks of D3 or D4 within the year) are not consistently significant, suggesting that a brief spell of extreme or exceptional dryness has a smaller effect on herd management decisions. This finding supports the idea that the impact of drought accelerates once producers endure multiple weeks of high-severity conditions, even if those weeks are not necessarily consecutive.

Interaction terms further show that LFP coverage can partially offset these losses when drought crosses these multiweek thresholds. In particular, 5 months of LFP payments mitigate around 0.303 percent of herd losses per week of D4 dryness, and 4 months of payments provide a substantial 0.227 percent reduction for long D3. Because these recurrent droughts are the ones that meaningfully alter herd decisions, it follows that only the higher-tier payments triggered by multiweek D3/D4 events have a clear effect.  Meanwhile, 3 months and 1 month of coverages are generally inconsequential.

Overall, these results lend empirical support to a tiered benefits structure: more weeks of D3 or D4 conditions (whether consecutive or not) suggest a negative impact on herds, and lead to more consequential multi-month LFP payments. A spline model, provided in Table A5 (Appendix), further demonstrates the nonlinearity of these drought effects, although beyond 27 weeks the estimates become less interpretable due to sparse data—particularly for D4.

### 5.2.2 Consecutive Weeks: Equation 4.3

Equation 4.3 measures drought severity by the longest consecutive spell of each drought level within a given year, rather than summing weekly totals. This approach aims to capture whether a sustained run of dryness exerts a distinct influence on herd sizes. However, it also introduces new interpretive challenges.

First, the maximum-run variables can overlap with prior-year drought. A twelve-week D3 spell beginning in October, for instance, will split across two calendar years. If the model includes an LDV, the prior year's inventory may absorb much of that earlier exposure, undercutting the ability to detect its full impact. For this reason, we focus primarily on baseline and weighted only specifications, which omits the LDV. Second, the categories are not mutually exclusive. For example, D0+, D1+, and D2+

runs may include weeks that progress to D3+, creating “mixed intensity” episodes that complicate a clean separation of effects.

Despite these challenges, the baseline results still offer useful comparisons. From Table 11, each week of a D4 run corresponds to a 0.152 percent decline in cattle inventories—less than the –0.273 percent found in the cumulative baseline model. One way to reconcile this difference is to consider that a “week of D4” also counts toward longer runs of D3+, D2+, D1+, and D0+. If we combine their respective coefficients—for instance, –0.056 percent for D1+ plus –0.090 percent for D3+ plus –0.160 percent for D4—the total approaches –0.298 percent, nearly matching the –0.273 percent benchmark for D4 alone in Equation 4.1. The higher coefficient might suggest that consecutive weeks of drought impose greater harm than a single, isolated week, but the two are not statistically distinguishable. Regardless, because D0 and D2 effects are typically small or insignificant, fully aligning these approaches remains somewhat uncertain.

Interestingly, while one might expect D2 drought to surpass D1 in its impact, the opposite appears: D2 stays insignificant, even when measured consecutively, whereas D1 can be weakly significant in some specifications, cumulative and consecutive. One explanation could be that producers are generally prepared to handle D2 (for example, by supplementing feed) and thus do not drastically reduce herds, whereas D1 in certain contexts may coincide with, or signal the onset of, more severe drought. Another possibility is that USDA’s classification thresholds for D1 vs. D2 do not map perfectly onto real-world stressors for cattle, making D1 conditions appear more disruptive in certain local contexts. Either explanation is not totally satisfying.

These results are also consistent the findings of Hrozencik et al. (2024), who find that 1 month of LFP payments (triggered by eight consecutive weeks of D2) do little to alter herd inventories, suggesting D2 drought alone often does not provoke large-scale liquidation. In short, if D2 conditions do not truly harm operations, producers have little reason to reduce herd sizes, and the data show no strong statistical effect or policy implication for these D2 drought episodes.

### 5.2.3 Mixed Model: Equation 4.4

Equation 4.4 merges both segmentation (short vs. long) for D3/D4 and run-length measures for D0–D2, mirroring LFP's tiered structure more precisely. By design, it splits high-severity droughts into distinct segments (e.g., short D3, long D4) while also tracking whether a county experiences multiweek runs of lower-severity dryness (D0–D2). Although this approach closely follows LFP rules, it can create overlapping definitions that, in practice, disperse the total drought impact across different variables.

One result is that the coefficients on long-duration D3 and D4 are somewhat smaller compared to Equation 4.2, because the D0–D2 max-run terms pick up part of the same dry spells. For instance, a week of D4 can also be classified as a multiweek run of D3+, D2+, and so on. Thus, the negative effect associated with severe drought may be "shared" across overlapping variables, leading to slightly understated coefficients for high-severity dryness (e.g., −0.242% vs. −0.289%). D0–D2 terms, however, remain statistically insignificant. Short D3 also shows up with a counterintuitive positive sign with borderline significance, possibly because counties experiencing only a brief D3 episode—but minimal D2—often enjoy relatively favorable overall conditions. However, this effect is statistically fragile: in the herd-weighted regressions in Table A3 (Appendix), the coefficient on short D3 ceases to be significant. Nevertheless, extended D3 and D4 drought still drive the largest herd reductions, and the multi-tier LFP coverage structure continues to mitigate these losses under severe, multiweek dryness.

### 5.2.4 Summary

The refined measures of drought exposure—whether through threshold durations, sustained spells, or an integrated hybrid—consistently demonstrate that long-duration D3 and D4 droughts exert significant negative impacts on cattle inventories. The interaction effects suggest that higher-tier LFP coverage appears to offset this.

## 5.3 Robustness Checks

To assess whether the main conclusions hold under alternative data choices and variable definitions, Table 12 presents four variations on the baseline specification. Each column modifies Equation (4.1) by adjusting which drought variables or controls are included and by restricting the sample:

Table 12: Robustness Check using Equation 4.1 Regression Results

| | (1) Using Dominant Drought Variables | (2) Excluding 2014 and 2015 | (3) No Irrigation Controls (Full Panel) | (4) No Irrigation Controls (Trimmed) |
|---|---|---|---|---|
| *Drought Conditions* | | | | |
| L1: Weeks in D0 | 0.00010 | 0.00015 | 0.00020 | 0.00015 |
| | (0.00023) | (0.00023) | (0.00019) | (0.00022) |
| L1: Weeks in D1 | -0.00068*** | -0.00036 | -0.00033* | -0.00031 |
| | (0.00022) | (0.00023) | (0.00018) | (0.00022) |
| L1: Weeks in D2 | -0.00003 | 0.00024 | 0.00020 | 0.00001 |
| | (0.00029) | (0.00028) | (0.00022) | (0.00025) |
| L1: Weeks in D3 | -0.00107*** | -0.00097*** | -0.00110*** | -0.00107*** |
| | (0.00030) | (0.00032) | (0.00027) | (0.00030) |
| L1: Weeks in D4 | -0.00272*** | -0.00306*** | -0.00266*** | -0.00272*** |
| | (0.00045) | (0.00046) | (0.00043) | (0.00045) |
| *LFP Payments* | | | | |
| L1: 1 Month of LFP | -0.00919 | -0.00987 | 0.00229 | -0.00919 |
| | (0.02503) | (0.02968) | (0.02467) | (0.02503) |
| L1: 3 Months of LFP | -0.00243 | -0.00569 | -0.00061 | -0.00243 |
| | (0.01364) | (0.01454) | (0.01230) | (0.01364) |
| L1: 4 Months of LFP | -0.01538 | -0.01891 | -0.00343 | -0.01538 |
| | (0.01357) | (0.01491) | (0.01205) | (0.01357) |
| L1: 5 Months of LFP | 0.01266 | 0.01695 | 0.03170* | 0.01266 |
| | (0.01968) | (0.02142) | (0.01895) | (0.01968) |
| *Interactions* | | | | |
| L1: D2 x 1 LFP | 0.00054 | 0.00030 | 0.00020 | 0.00054 |
| | (0.00108) | (0.00151) | (0.00103) | (0.00108) |
| L1: D3 x 3 LFP | -0.00050 | -0.00036 | 0.00114 | -0.00050 |
| | (0.00187) | (0.00196) | (0.00183) | (0.00187) |
| L1: D3 x 4 LFP | 0.00197** | 0.00210** | 0.00178** | 0.00197** |
| | (0.00078) | (0.00088) | (0.00070) | (0.00078) |
| L1: D4 x 4 LFP | 0.00004 | 0.00139 | -0.00040 | 0.00004 |
| | (0.00219) | (0.00213) | (0.00208) | (0.00219) |
| L1: D4 x 5 LFP | 0.00296*** | 0.00375*** | 0.00254*** | 0.00296*** |
| | (0.00083) | (0.00088) | (0.00079) | (0.00083) |
| *Controls* | | | | |
| L1: Unemployment | 0.00076 | -0.00002 | -0.00129 | 0.00076 |
| | (0.00245) | (0.00242) | (0.00221) | (0.00245) |
| L1: Irrigation | -0.00081* | -0.00130** | - | - |
| | (0.00048) | (0.00055) | | |
| Year Fixed Effects | Yes | Yes | Yes | Yes |
| County Fixed Effects | Yes | Yes | Yes | Yes |
| Observations | 16,215 | 14,805 | 21,804 | 16,215 |
| Counties | 705 | 705 | 948 | 705 |
| Constant | 9.16764*** | 9.19610*** | 9.07484*** | 9.16764*** |
| | (.01829) | (.01840) | (.01290) | (0.01475) |
| $R^2$ (Within) | 0.09500 | 0.09830 | 0.09690 | 0.09500 |
| $R^2$ (Between) | 0.07390 | 0.03020 | 0.01090 | 0.07390 |
| $R^2$ (Overall) | 0.00070 | 0.01240 | 0.00200 | 0.00070 |
| F Statistic | 51.45 | 48.61 | 68.00 | 51.45 |

Notes: Standard errors clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Column (1) uses a “dominant” drought measure instead of the maximum-severity approach, while column (2) excludes 2014 and 2015 to address any distortions from the retroactive LFP payments that began in 2014. In columns (3) and (4), I remove the irrigation controls, first using the full panel and then a trimmed sample, to check whether irrigation variables drive the main results. Across all these variations, the central finding remains the same: higher-intensity drought has a significant negative impact on herd inventories, and extended LFP coverage (particularly the 5 month tier) offsets much of this effect. I conduct more robustness tests in Table A7 (Appendix).

5.3.1 Placebo Tests

To confirm that the main results are not driven by unobserved trends anticipating future drought or LFP coverage, two placebo specifications introduce lead variables. One model uses next year’s drought categories, and the other next year’s LFP tiers. In both cases, the lead variables generally fail to predict current herd outcomes, indicating no strong “pre-trend” bias in the data. The complete results appear in Table A8 (Appendix), where only D0 in the future attains significance. Overall, these findings support the conclusion that current and past drought conditions—and past LFP coverage—explain changes in herd sizes, rather than counties somehow preemptively adjusting for next year’s extreme dryness or future payments.

### 5.4 Limitations and Further Research

This paper offers new evidence on how cattle inventories respond to drought and the mitigating role of LFP. Nevertheless, several limitations merit discussion. Chief among these is the lack of data on county-level grazing periods, which Hrozencik et al. (2024) utilized through their study within the USDA and ERS. Without this data, the analysis cannot capture the precise overlap between drought and active grazing windows, which vary across regions and time. This limitation hampers weighting drought exposure by seasonal importance—a refinement that could reveal whether droughts during peak grazing months lead to sharper inventory declines. Additionally, because LFP eligibility hinges on drought coinciding with defined grazing periods, the interaction terms in our models may incorporate droughts that fall outside eligibility windows, introducing measurement error. Additionally, it may bias down our estimates of untreated D3 and D4, if droughts during grazing period have a smaller impact of herd management choices.

A second limitation relates to the identification of extreme drought episodes. While the segmented and consecutive-weeks models help uncover nonlinearities, D3 and D4 drought events remain rarer. This sparsity reduces precision and may obscure meaningful heterogeneity in cattle producers' responses to prolonged drought.

Technological change presents a further challenge. Innovations such as drought-tolerant forage, improved watering systems, or breed substitution (e.g., greater use of Brahman cattle) may attenuate the relationship between drought exposure and inventory loss. The analysis does not control for such improvements, as data is limited. As a result, it is difficult to distinguish the effect of LFP from that of evolving management practices. Future research could explore this channel more directly, perhaps using breed registration data or USDA surveys.

In addition, nonlinear models could be refined using longer time series that capture more D3 and D4 events. Specifically, one could use the matching approach of Hrozencik et al. 2024 to look at the 3, 4, and 5 months of payments. This currently presents a challenge as all counties experiencing any amount of D3 and D4 drought receive payments. Another promising direction involves modeling spatial spillovers, similarly to Kuwayama et al. (2018). Drought-induced herd reductions in one county may shift cattle to neighboring areas, influencing outcomes in ways not captured by current specifications.

Capturing such dynamics would allow for a more complete assessment of how local and regional adaptation shapes aggregate impacts. Taken together, these extensions would help isolate the effects of drought and federal assistance.

## 6 Conclusion

This paper explores how drought affects U.S. cattle inventories and whether multi-month tiers of the Livestock Forage Disaster Program (LFP) meaningfully soften these impacts—a topic absent from much of the existing literature on this disaster assistance. Using county-level data from 2000 to 2023, drawn from USDA NASS inventories and U.S. Drought Monitor records, the analysis employs a two-way fixed-effects framework to isolate drought's direct effect and LFP's moderating role. Results show that extreme (D3–D4) dryness drives substantial declines in cattle inventories, yet multi-month LFP coverage partially or even completely offsets these losses. Crucially, these findings matter not just for ranchers on the brink of liquidation; by preventing steep drops in herd sizes, LFP also helps temper the inflationary ripple effects that reduced cattle populations can have on beef prices. Ultimately, this study highlights that persistent, high-severity drought meaningfully shrinks cattle herds, but well-targeted LFP assistance can moderate these impacts, safeguarding both producers and the broader beef supply chain.

## Reference List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# Appendix

## A. Supplemental Specifications and Robustness Tests

Table A1: Equation 4.2 Regression Results

| | (1) Base | (2) + Lagged DV | (3) + Weights | (4) + Lag & Weights |
|---|---|---|---|---|
| L1: ln(Cattle) | | 0.78253*** | | 0.76910*** |
| | | (0.00837) | | (0.00810) |
| L1: Max Run D0+ | 0.00020 | 0.00021* | -0.00028 | -0.00011 |
| | (0.00024) | (0.00013) | (0.00019) | (0.00012) |
| L1: Max Run D1+ | -0.00056* | -0.00032* | -0.00028 | -0.00016 |
| | (0.00033) | (0.00017) | (0.00035) | (0.00016) |
| L1: Max Run D2+ | -0.00001 | -0.00018 | -0.00005 | 0.00011 |
| | (0.00037) | (0.00021) | (0.00043) | (0.00018) |
| L1: Max Run D3+ | -0.00090** | -0.00034 | -0.00071* | -0.00033 |
| | (0.00042) | (0.00027) | (0.00037) | (0.00023) |
| L1: Max Run D4 | -0.00152** | -0.00050 | -0.00090* | -0.00065** |
| | (0.00059) | (0.00038) | (0.00050) | (0.00033) |
| L1: 1 Month of LFP | 0.00224 | -0.01442 | 0.00966 | -0.01330 |
| | (0.02485) | (0.01099) | (0.01725) | (0.01111) |
| L1: 3 Months of LFP | -0.00233 | -0.00162 | 0.00879 ( | -0.00264 |
| | (0.01342) | (0.00737) | 0.01222) | (0.00549) |
| L1: 4 Months of LFP | -0.00852 | -0.01463** | -0.02172* | -0.00984 |
| | (0.01363) | (0.00711) | (0.01338) | (0.00657) |
| L1: 5 Months of LFP | 0.01437 | -0.00813 | 0.03084* | -0.01007 |
| | (0.01968) | (0.00877) | (0.01655) | (0.00828) |
| L1: D2+ x 1 LFP | 0.00017 | 0.00071 | 0.00057 | 0.00067 |
| | (0.00106) | (0.00053) | (0.00082) | (0.00046) |
| L1: D3+ x 3 LFP | -0.00034 | 0.00024 | -0.00028 | 0.00045 |
| | (0.00191) | (0.00088) | (0.00152) | (0.00066) |
| L1: D3+ x 4 LFP | 0.00198** | 0.00161*** | 0.00237*** | 0.00113*** |
| | (0.00084) | (0.00039) | (0.00079) | (0.00033) |
| L1: D4 x 4 LFP | -0.00298 | -0.00053 | -0.00310* | -0.00122 |
| | (0.00221) | (0.00098) | (0.00162) | (0.00098) |
| L1: D4 x 5 LFP | 0.00294*** | 0.00199*** | 0.00149** | 0.00226*** |
| | (0.00088) | (0.00049) | (0.00068) | (0.00051) |
| L1: Unemployment | 0.00071 | -0.00041 | 0.00070 | -0.00027 |
| | (0.00244) | (0.00099) | (0.00189) | (0.00085) |
| L1: Irrigation | -0.00123** | -0.00027* | -0.00080* | -0.00041*** |
| | (0.00055) | (0.00015) | (0.00048) | (0.00014) |
| Year Fixed Effects | Yes | Yes | Yes | Yes |
| County Fixed Effects | Yes | Yes | Yes | Yes |
| Observations | 16,215 | 16,215 | 16,215 | 16,215 |
| Counties | 705 | 705 | 705 | 705 |
| Constant | 9.19457*** | 1.99526*** | 9.95273*** | 2.30122*** |
| | (0.018478) | (0.07823) | (0.01578) | (0.08002) |
| $R^2$ (Within) | 0.09660 | 0.65060 | 0.10410 | 0.63840 |
| $R^2$ (Between) | 0.01740 | 0.99970 | 0.00480 | 0.99970 |
| $R^2$ (Overall) | 0.00910 | 0.98820 | 0.00490 | 0.98810 |
| F Statistic | 47.71 | 525.06 | 69.62 | 675.54 |
| Mean of Dep. Var. | 9.19457 | 1.99526 | 9.95273 | 2.30122 |
| | (1) Base | (2) + Lagged DV | (3) + Weights | (4) + Lag & Weights |

Notes: Standard errors clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table A2: Equation 4.3 Regression Results

| | (1) Base | (2) + Lagged DV | (3) + Weights | (4) + Lag & Weights |
|---|---|---|---|---|
| L1: ln(Cattle) | | 0.78253*** | | 0.76910*** |
| | | (0.00837) | | (0.00810) |
| L1: Max Run D0+ | 0.00020 | 0.00021* | -0.00028 | -0.00011 |
| | (0.00024) | (0.00013) | (0.00019) | (0.00012) |
| L1: Max Run D1+ | -0.00056* | -0.00032* | -0.00028 | -0.00016 |
| | (0.00033) | (0.00017) | (0.00035) | (0.00016) |
| L1: Max Run D2+ | -0.00001 | -0.00018 | -0.00005 | 0.00011 |
| | (0.00037) | (0.00021) | (0.00043) | (0.00018) |
| L1: Max Run D3+ | -0.00090** | -0.00034 | -0.00071* | -0.00033 |
| | (0.00042) | (0.00027) | (0.00037) | (0.00023) |
| L1: Max Run D4 | -0.00152** | -0.00050 | -0.00090* | -0.00065** |
| | (0.00059) | (0.00038) | (0.00050) | (0.00033) |
| L1: 1 Month of LFP | 0.00224 | -0.01442 | 0.00966 | -0.01330 |
| | (0.02485) | (0.01099) | (0.01725) | (0.01111) |
| L1: 3 Months of LFP | -0.00233 | -0.00162 | 0.00879 ( | -0.00264 |
| | (0.01342) | (0.00737) | 0.01222) | (0.00549) |
| L1: 4 Months of LFP | -0.00852 | -0.01463** | -0.02172* | -0.00984 |
| | (0.01363) | (0.00711) | (0.01338) | (0.00657) |
| L1: 5 Months of LFP | 0.01437 | -0.00813 | 0.03084* | -0.01007 |
| | (0.01968) | (0.00877) | (0.01655) | (0.00828) |
| L1: D2+ x 1 LFP | 0.00017 | 0.00071 | 0.00057 | 0.00067 |
| | (0.00106) | (0.00053) | (0.00082) | (0.00046) |
| L1: D3+ x 3 LFP | -0.00034 | 0.00024 | -0.00028 | 0.00045 |
| | (0.00191) | (0.00088) | (0.00152) | (0.00066) |
| L1: D3+ x 4 LFP | 0.00198** | 0.00161*** | 0.00237*** | 0.00113*** |
| | (0.00084) | (0.00039) | (0.00079) | (0.00033) |
| L1: D4 x 4 LFP | -0.00298 | -0.00053 | -0.00310* | -0.00122 |
| | (0.00221) | (0.00098) | (0.00162) | (0.00098) |
| L1: D4 x 5 LFP | 0.00294*** | 0.00199*** | 0.00149** | 0.00226*** |
| | (0.00088) | (0.00049) | (0.00068) | (0.00051) |
| L1: Unemployment | 0.00071 | -0.00041 | 0.00070 | -0.00027 |
| | (0.00244) | (0.00099) | (0.00189) | (0.00085) |
| L1: Irrigation | -0.00123** | -0.00027* | -0.00080* | -0.00041*** |
| | (0.00055) | (0.00015) | (0.00048) | (0.00014) |
| Year Fixed Effects | Yes | Yes | Yes | Yes |
| County Fixed Effects | Yes | Yes | Yes | Yes |
| Observations | 16,215 | 16,215 | 16,215 | 16,215 |
| Counties | 705 | 705 | 705 | 705 |
| Constant | 9.19457*** | 1.99526*** | 9.95273*** | 2.30122*** |
| | (0.01807) | (.07792) | (.01543) | (0.07971) |
| $R^2$ (Within) | 0.09660 | 0.65060 | 0.10410 | 0.63840 |
| $R^2$ (Between) | 0.01740 | 0.99970 | 0.00480 | 0.99970 |
| $R^2$ (Overall) | 0.00910 | 0.98820 | 0.00490 | 0.98810 |
| F Statistic | 47.71 | 525.06 | 69.62 | 675.54 |
| Mean of Dep. Var. | 9.19457 | 1.99526 | 9.95273 | 2.30122 |

Notes: Standard errors clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table A3: Equation 4.4 Regression Results

| | (1) Base | (2) + Lagged DV | (3) + Weights | (4) + Lag & Weights |
|---|---|---|---|---|
| L1: ln(Cattle) | - | 0.78258*** | - | 0.76912*** |
| | | (0.00839) | | (0.00812) |
| L1: Max Run D0+ | 0.00015 | 0.00021* | -0.00032* | -0.00012 |
| | (0.00024) | (0.00013) | (0.00019) | (0.00011) |
| L1: Max Run D1+ | -0.00059* | -0.00033* | -0.00029 | -0.00017 |
| | (0.00033) | (0.00017) | (0.00035) | (0.00016) |
| L1: Max Run D2+ | -0.00011 | -0.00018 | -0.00014 | 0.00011 |
| | (0.00037) | (0.00021) | (0.00044) | (0.00018) |
| L1: Short D3 | 0.00406* | -0.00069 | 0.00313 | 0.00016 |
| | (0.00216) | (0.00153) | (0.00214) | (0.00127) |
| L1: Long D3 | -0.00110** | -0.00036 | -0.00091** | -0.00045* |
| | (0.00043) | (0.00028) | (0.00041) | (0.00024) |
| L1: Short D4 | -0.00188 | 0.00304 | -0.00139 | 0.00208 |
| | (0.00335) | (0.00205) | (0.00289) | (0.00178) |
| L1: Long D4 | -0.00242*** | -0.00118*** | -0.00150** | -0.00124*** |
| | (0.00065) | (0.00041) | (0.00063) | (0.00035) |
| L1: 1 Month of LFP | 0.00403 | -0.01446 | 0.01105 | -0.01299 |
| | (0.02497) | (0.01101) | (0.01731) | (0.01117) |
| L1: 3 Months of LFP | 0.03119 | 0.01013 | 0.03680 | -0.00088 |
| | (0.02957) | (0.01779) | (0.02630) | (0.01365) |
| L1: 4 Months of LFP | -0.01146 | -0.00940 | -0.02232 | -0.00817 |
| | (0.01406) | (0.00788) | (0.01430) | (0.00699) |
| L1: 5 Months of LFP | 0.01678 | -0.01058 | 0.03162* | -0.01102 |
| | (0.02068) | (0.00943) | (0.01670) | (0.00858) |
| L1: D2+ x 1 LFP | 0.00018 | 0.00072 | 0.00059 | 0.00066 |
| | (0.00106) | (0.00052) | (0.00082) | (0.00046) |
| L1: Short D3 x 3 LFP | -0.01917 | -0.00423 | -0.01596 | -0.00002 |
| | (0.01252) | (0.00691) | (0.01064) | (0.00563) |
| L1: Long D3 x 4 LFP | 0.00224*** | 0.00160*** | 0.00259*** | 0.00127*** |
| | (0.00081) | (0.00040) | (0.00079) | (0.00033) |
| L1: Short D4 x 4 LFP | -0.01213 | -0.00387 | -0.01094 | -0.00583** |
| | (0.00759) | (0.00313) | (0.00724) | (0.00297) |
| L1: Long D4 x 5 LFP | 0.00298*** | 0.00221*** | 0.00142* | 0.00245*** |
| | (0.00093) | (0.00053) | (0.00073) | (0.00056) |
| L1: Unemployment | 0.00072 | -0.00041 | 0.00070 | -0.00023 |
| | (0.00244) | (0.00099) | (0.00189) | (0.00085) |
| L1: Irrigation | -0.00123** | -0.00028* | -0.00081* | -0.00042*** |
| | (0.00055) | (0.00015) | (0.00048) | (0.00014) |
| Year Fixed Effects | Yes | Yes | Yes | Yes |
| County Fixed Effects | Yes | Yes | Yes | Yes |
| Observations | 16,215 | 16,215 | 16,215 | 16,215 |
| Counties | 705 | 705 | 705 | 705 |
| Constant | 9.19377*** | 1.99466*** | 9.95267*** | 2.30085*** |
| | (0.01805) | (0.07814) | (0.01540) | (0.07995) |
| $R^2$ (Within) | 0.09710 | 0.65060 | 0.10450 | 0.63840 |
| $R^2$ (Between) | 0.01720 | 0.99970 | 0.00490 | 0.99970 |
| $R^2$ (Overall) | 0.00910 | 0.98820 | 0.00490 | 0.98810 |
| F Statistic | 46.81 | 505.16 | 67.32 | 638.47 |

Notes: Standard errors clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table A4: Results from Equation 4.1 with Alternative Drought Aggregation (D0–D2 Combined)

| | (1) Base | (2) + Lagged DV | (3) + Weights | (4) + Lag & Weights |
|---|---|---|---|---|
| L1: ln(Cattle) | - | 0.78111*** | p | 0.76864*** |
| | | (0.00853) | | (0.00811) |
| L1: Low Drought (D0–D2) | -0.00011 | -0.00001 | -0.00039*** | -0.00015** |
| | (0.00013) | (0.00008) | (0.00012) | (0.00007) |
| L1: Weeks in D3 | -0.00111*** | -0.00063*** | -0.00128*** | -0.00049*** |
| | (0.00030) | (0.00018) | (0.00029) | (0.00017) |
| L1: Weeks in D4 | -0.00275*** | -0.00103*** | -0.00211*** | -0.00103*** |
| | (0.00046) | (0.00025) | (0.00038) | (0.00022) |
| L1: 1 Month of LFP | -0.08286* | -0.03355** | -0.04897 | -0.03030* |
| | (0.04288) | (0.01473) | (0.03524) | (0.01559) |
| L1: 3 Months of LFP | -0.00397 | -0.00276 | 0.00815 | -0.00242 |
| | (0.01364) | (0.00722) | (0.01227) | (0.00549) |
| L1: 4 Months of LFP | -0.01628 | -0.01991*** | -0.02857** | -0.01273** |
| | (0.01338) | (0.00705) | (0.01344) | (0.00642) |
| L1: 5 Months of LFP | 0.00991 | -0.01007 | 0.02947* | -0.01003 |
| | (0.01944) | (0.00907) | (0.01610) | (0.00865) |
| L1: Low Drought x 1 LFP | 0.00209* | 0.00069** | 0.00154* | 0.00067* |
| | (0.00109) | (0.00034) | (0.00088) | (0.00035) |
| L1: D3 x 3 LFP | -0.00051 | 0.00012 | -0.00043 | 0.00038 |
| | (0.00188) | (0.00091) | (0.00151) | (0.00070) |
| L1: D3 x 4 LFP | 0.00196** | 0.00163*** | 0.00241*** | 0.00119*** |
| | (0.00078) | (0.00037) | (0.00074) | (0.00031) |
| L1: D4 x 4 LFP | 0.00001 | 0.00109 | -0.00017 | -0.00004 |
| | (0.00221) | (0.00080) | (0.00165) | (0.00086) |
| L1: D4 x 5 LFP | 0.00297*** | 0.00191*** | 0.00143** | 0.00213*** |
| | (0.00082) | (0.00046) | (0.00064) | (0.00050) |
| L1: Unemployment | 0.00057 | -0.00043 | 0.00052 | -0.00031 |
| | (0.00242) | (0.00099) | (0.00190) | (0.00085) |
| L1: Irrigation | -0.00123** | -0.00028* | -0.00080* | -0.00042*** |
| | (0.00055) | (0.00015) | (0.00048) | (0.00014) |
| Year Fixed Effects | Yes | Yes | Yes | Yes |
| County Fixed Effects | Yes | Yes | Yes | Yes |
| Observations | 16,215 | 16,215 | 16,215 | 16,215 |
| Counties | 705 | 705 | 705 | 705 |
| Constant | 9.19575*** | 2.00799*** | 9.95589*** | 2.30717*** |
| | (0.01850) | (0.07806) | (0.01569) | (0.07972) |
| $R^2$ (Within) | 0.09660 | 0.64940 | 0.10350 | 0.63790 |
| $R^2$ (Between) | 0.02130 | 0.99970 | 0.00600 | 0.99970 |
| $R^2$ (Overall) | 0.01000 | 0.98810 | 0.00520 | 0.98810 |
| F Statistic | 50.52 | 553.92 | 70.09 | 690.52 |

Notes: Standard errors clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table A5: Regression Results with 3-Knot Splines for D3 and D4 Drought Exposure

| | (1) Base | (2) + Lagged DV | (3) + Weights | (4) + Lag & Weights |
|---|---|---|---|---|
| L1: ln(Cattle) | | 0.78135*** | | 0.76877*** |
| | | (0.00854) | | (0.00816) |
| L1: Weeks in D0 | 0.00012 | 0.00023* | -0.00022 | -0.00013 |
| | (0.00022) | (0.00012) | (0.00019) | (0.00011) |
| L1: Weeks in D1 | -0.00040* | -0.00010 | -0.00042* | -0.00021* |
| | (0.00022) | (0.00012) | (0.00025) | (0.00011) |
| L1: Weeks in D2 | -0.00028 | -0.00022 | -0.00073*** | -0.00024* |
| | (0.00026) | (0.00016) | (0.00026) | (0.00014) |
| L1: D3 Spline 0–8 Weeks | 0.00185* | 0.00057 | 0.00092 | 0.00064 |
| | (0.00099) | (0.00068) | (0.00096) | (0.00055) |
| L1: D3 Spline 9–26 Weeks | -0.00242*** | -0.00176*** | -0.00231*** | -0.00155*** |
| | (0.00066) | (0.00052) | (0.00068) | (0.00044) |
| L1: D3 Spline 27+ Weeks | -0.00206** | 0.00100 | -0.00119 | 0.00067 |
| | (0.00104) | (0.00059) | (0.00085) | (0.00045) |
| L1: D4 Spline 0–8 Weeks | -0.00332** | -0.00014 | -0.00210* | -0.00003 |
| | (0.00147) | (0.00082) | (0.00126) | (0.00071) |
| L1: D4 Spline 9–26 Weeks | -0.00350*** | -0.00150** | -0.00312*** | -0.00206*** |
| | (0.00123) | (0.00072) | (0.00105) | (0.00061) |
| L1: D4 Spline 27+ Weeks | -0.00129 | -0.00141 | -0.00060 | -0.00034 |
| | (0.00144) | (0.00094) | (0.00134) | (0.00090) |
| L1: 1 Month of LFP | -0.00848 | -0.01765 | 0.00108 | -0.01485 |
| | (0.02516) | (0.01076) | (0.01777) | (0.01112) |
| L1: 3 Months of LFP | 0.01149 | 0.00227 | 0.01731 | -0.00211 |
| | (0.01838) | (0.00993) | (0.01597) | (0.00743) |
| L1: 4 Months of LFP | -0.01890 | -0.01312* | -0.02000 | -0.01124 |
| | (0.01336) | (0.00748) | (0.01349) | (0.00643) |
| L1: 5 Months of LFP | 0.01529 | -0.00564 | 0.02851 | 0.00001 |
| | (0.02296) | (0.01054) | (0.01935) | (0.00950) |
| L1: D2 x 1 LFP | 0.00066 | 0.00084* | 0.00101 | 0.00069 |
| | (0.00108) | (0.00046) | (0.00080) | (0.00043) |
| L1: D3 (0–8) x 3 LFP | -0.00654 | -0.00125 | -0.00407 | -0.00001 |
| | (0.00469) | (0.00228) | (0.00363) | (0.00183) |
| L1: D3 (9–26) x 4 LFP | 0.00416*** | 0.00282*** | 0.00336** | 0.00233*** |
| | (0.00138) | (0.00077) | (0.00144) | (0.00072) |
| L1: D3 (27+) x 4 LFP | 0.00085 | -0.00010 | 0.00207 | -0.00026 |
| | (0.00191) | (0.00083) | (0.00150) | (0.00067) |
| L1: D4 (0–8) x 4 LFP | -0.00364 | 0.00017 | -0.00364 | -0.00128 |
| | (0.00390) | (0.00153) | (0.00369) | (0.00153) |
| L1: D4 (9–26) x 5 LFP | 0.00617** | 0.00310 | 0.00345 | 0.00261 |
| | (0.00306) | (0.00196) | (0.00237) | (0.00174) |
| L1: D4 (27+) x 5 LFP | -0.00073 | 0.00165 | -0.00083 | 0.00204 |
| | (0.00260) | (0.00212) | (0.00224) | (0.00230) |
| L1: Unemployment | 0.00058 | -0.00028 | 0.00067 | -0.00022 |
| | (0.00244) | (0.00099) | (0.00189) | (0.00084) |
| L1: Irrigation | -0.00123** | -0.00029* | -0.00080* | -0.00042*** |
| | (0.00055) | (0.00015) | (0.00048) | (0.00014) |
| Year Fixed Effects | Yes | Yes | Yes | Yes |
| County Fixed Effects | Yes | Yes | Yes | Yes |
| Observations | 16,215 | 16,215 | 16,215 | 16,215 |
| Counties | 705 | 705 | 705 | 705 |
| Constant | 9.19335*** | 2.00393*** | 9.95389*** | 2.30519*** |
| | (0.01846) | (0.07824) | (0.01575) | (0.08022) |
| $R^2$ (Within) | 0.09750 | 0.64980 | 0.10440 | 0.63830 |
| $R^2$ (Between) | 0.01900 | 0.99970 | 0.00420 | 0.99970 |
| $R^2$ (Overall) | 0.00950 | 0.98820 | 0.00470 | 0.98810 |
| F Statistic | 43.01 | 469.74 | 60.33 | 584.03 |

Notes: This table presents results from spline regressions (Equation 4.2) using piecewise linear segments for D3 and D4 drought durations. Standard errors are clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A6. Equation 4.1 Regression Results Comparing Unlagged vs. Lagged Covariates

| L1: ln(Cattle) | (1)<br>Covariates Unlagged | | (2)<br>Covariates L2 | (3)<br>Covariates (L1 and L2) |
|---|---|---|---|---|
| Weeks in D0 | -0.00019 | L1: Weeks in D0 | 0.00049** | 0.00010 |
| | (0.00022) | | (0.00021) | (0.00021) |
| | | L2: Weeks in D0 | | 0.00048** |
| | | | | (0.00020) |
| Weeks in D1 | -0.00031 | L1:Weeks in D1 | 0.00021 | -0.00036* |
| | (0.00022) | | (0.00020) | (0.00020) |
| | | L2:Weeks in D1 | | 0.00023 |
| | | | | (0.00019) |
| Weeks in D2 | 0.00010 | L1:Weeks in D2 | 0.00004 | 0.00006 |
| | (0.00026) | | (0.00027) | (0.00023) |
| | | L2:Weeks in D2 | | 0.00008 |
| | | | | (0.00026) |
| Weeks in D3 | -0.00085*** | L1:Weeks in D3 | -0.00067** | -0.00110*** |
| | (0.00031) | | (0.00029) | (0.00028) |
| | | L2:Weeks in D3 | | -0.00034 |
| | | | | (0.00026) |
| Weeks in D4 | -0.00224*** | L1:Weeks in D4 | -0.00271*** | -0.00211*** |
| | (0.00040) | | (0.00044) | (0.00037) |
| | | L2:Weeks in D4 | | -0.00206*** |
| | | | | (0.00035) |
| 1 Month of LFP | 0.00877 | L1: 1 Month of LFP | 0.00463 | -0.00642 |
| | (0.02335) | | (0.02542) | (0.02499) |
| | | L1: 1 Month of LFP | | 0.00273 |
| | | | | (0.02640) |
| 3 Months of LFP | -0.01368 | L2: 3 Months of LFP | 0.02772* | -0.00056 |
| | (0.01627) | | (0.01582) | (0.01341) |
| | | L2: 3 Months of LFP | | 0.02503 |
| | | | | (0.01579) |
| 4 Months of LFP | -0.00227 | L1: 4 Months of LFP | -0.00904 | -0.01607 |
| | (0.01324) | | (0.01524) | (0.01322) |
| | | L1: 4 Months of LFP | | -0.01140 |
| | | | | (0.01546) |
| 5 Months of LFP | 0.03388* | L2: 5 Months of LFP | -0.00326 | 0.01034 |
| | (0.01939) | | (0.02642) | (0.01795) |
| | | L2: 5 Months of LFP | | -0.01162 |
| | | | | (0.02655) |
| D2 x 1 LFP | -0.00079 | L1: D2 x 1 LFP | -0.00031 | 0.00034 |
| | (0.00104) | | (0.00117) | (0.00104) |
| | | L2: D2 x 1 LFP | | -0.00033 |
| | | | | (0.00117) |
| D3 x 3 LFP | 0.00022 | L1: D3 x 3 LFP | -0.00310 | -0.00030 |
| | (0.00191) | | (0.00260) | (0.00182) |
| | | L2: D3 x 3 LFP | | -0.00308 |
| | | | | (0.00252) |
| D3 x 4 LFP | 0.00088 | L1: D3 x 4 LFP | 0.00100 | 0.00208*** |
| | (0.00077) | | (0.00087) | (0.00071) |
| | | L2: D3 x 4 LFP | | 0.00064 |
| | | | | (0.00082) |
| D4 x 4 LFP | -0.00383 | L1: D4 x 4 LFP | 0.00369** | -0.00057 |
| | (0.00397) | | (0.00176) | (0.00226) |
| | | L2: D4 x 4 LFP | | 0.00277 |
| | | | | (0.00177) |
| D4 x 5LFP | 0.00080 | L1: D4 x 5LFP | 0.00311*** | 0.00267*** |
| | (0.00076) | | (0.00093) | (0.00077) |
| | | L2: D4 x 5 LFP | | 0.00237** |
| | | | | (0.00095) |
| Controls | Yes | | Yes | Yes |
| Fixed Effects | Yes | | Yes | Yes |
| Observations | 16,920 | | 15,510 | 15,510 |
| Counties | 705 | | 705 | 705 |
| Constant | 9.20443*** (0.01904) | | 9.18148*** (0.01756) | 9.18323*** (0.02028) |
| $R^2$ (Within) | 0.09490 | | 0.09800 | 0.10230 |
| $R^2$ (Between) | 0.02140 | | 0.02890 | 0.01540 |
| $R^2$ (Overall) | 0.01010 | | 0.01170 | 0.00880 |
| F Statistic | 56.61 | | 57.21 | 39.01 |

Notes: Standard errors clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table A7. Equation 4.1 Additional Robustness Checks

| | (1) Clustering Errors at State Level | (2) 2 LDVs | (3) Pre - 2014 | (4) Post - 2014 |
|---|---|---|---|---|
| L1: ln(Cattle) | | 0.80723*** | | |
| | | (0.01626) | | |
| L2: ln(Cattle) | | -0.05491*** | | |
| | | (0.01412) | | |
| L1: Weeks in D0 | 0.00015 | 0.00023* | 0.00006 | -0.00044 |
| | (0.00038) | (0.00012) | (0.00024) | (0.00028) |
| L1: Weeks in D1 | -0.00032 | -0.00009 | -0.00063*** | -0.00067** |
| | (0.00027) | (0.00012) | (0.00022) | (0.00033) |
| L1: Weeks in D2 | -0.00001 | -0.00015 | 0.00008 | -0.00053 |
| | (0.00028) | (0.00017) | (0.00027) | (0.00049) |
| L1: Weeks in D3 | -0.00108** | -0.00058*** | -0.00105*** | -0.00040 |
| | (0.00044) | (0.00019) | (0.00030) | (0.00080) |
| L1: Weeks in D4 | -0.00272*** | -0.00097*** | -0.00290*** | -0.00271 |
| | (0.00042) | (0.00025) | (0.00048) | (0.00586) |
| L1: 1 Month of LFP | -0.00892 | -0.01757* | - | -0.01143 |
| | (0.02689) | (0.01063) | | (0.02228) |
| L1: 3 Months of LFP | -0.00306 | 0.00001 | - | -0.01101 |
| | (0.01769) | (0.00724) | | (0.00953) |
| L1: 4 Months of LFP | -0.01561 | -0.01782** | - | -0.00806 |
| | (0.02170) | (0.00722) | | (0.01077) |
| L1: 5 Months of LFP | 0.01037 | -0.00823 | - | -0.02099 |
| | (0.01861) | (0.00920) | | (0.02129) |
| L1: D2 x 1 LFP | 0.00052 | 0.00078* | - | 0.00026 |
| | (0.00101) | (0.00045) | | (0.00113) |
| L1: D3 x 3 LFP | -0.00053 | 0.00009 | - | -0.00070 |
| | (0.00208) | (0.00089) | | (0.00150) |
| L1: D3 x 4 LFP | 0.00195* | 0.00163*** | - | 0.00077 |
| | (0.00107) | (0.00037) | | (0.00092) |
| L1: D4 x 4 LFP | 0.00007 | 0.00107 | - | -0.00246 |
| | (0.00184) | (0.00079) | | (0.00633) |
| L1: D4 x 5 LFP | 0.00298*** | 0.00182*** | - | 0.00271 |
| | (0.00070) | (0.00046) | | (0.00594) |
| L1: Unemployment | 0.00057 (0.00408) | 0.00020 (0.00104) | -0.00520* (0.00269) | -0.00248 (0.00350) |
| L1: Irrigation | -0.00123 (0.00078) | -0.00024 (0.00016) | -0.00108* (0.00065) | 0.00031 (0.00054) |
| Year Fixed Effects | Yes | Yes | Yes | Yes |
| County Fixed Effects | Yes | Yes | Yes | Yes |
| Observations | 16,215 | 15,510 | 9,165 | 6,345 |
| Counties | 705 | 705 | 705 | 705 |
| Constant | 9.19409*** | 2.27568*** | 9.21847*** | 9.08812*** |
| | (0.03582) | (0.09186) | (0.01986) | (0.02584) |
| $R^2$ (Within) | 0.09650 | 0.63240 | 0.09230 | 0.10370 |
| $R^2$ (Between) | 0.02100 | 0.99970 | 0.02780 | 0.09970 |
| $R^2$ (Overall) | 0.01000 | 0.98780 | 0.01250 | 0.00040 |
| F Statistic | - | 433.41 | 50.59 | 28.90 |

Notes: Standard errors clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Above are four supplementary robustness tests. Column (1) clusters standard errors at the state rather than county level. Since there are relatively few states compared to counties, this can inflate or dilute standard errors, yet the negative impact of D3 and D4 drought is still significant. Column (2) adds a second lag of the dependent variable, indicating that herd adjustments continue over multiple years. Column (3) restricts the sample to the pre-2014 period, showing that before the Farm Bill permanently established LFP, moderate (D1) and severe drought (D3 and D4) had a strong negative correlation with herd inventories. Finally, Column (4) focuses on the 2014–2023 window, when full LFP coverage was in place. Here, D1 remains negative and significant perhaps because it is not eligible for multi-month payments, while D3 and D4 no longer exhibit a strong negative effect. Generally, any D3 or D4 episodes after 2014 that are not covered by LFP must have occurred outside the county's grazing period, implying they do less damage to herds than droughts during active grazing seasons. As a result, these "untreated" D3/D4 episodes no longer appear nearly as harmful in the annual data, effectively shrinking the observed coefficient for severe drought.

Table A8. Placebo Tests

| | (1) Lead Droughts | | (3) Lead Payments |
|---|---|---|---|
| F1: Weeks in D0 | -0.00052*** | L1: Weeks in D0 | 0.00019 |
| | (0.00020) | | (0.00022) |
| F1: Weeks in D1 | 0.00019 | L1: Weeks in D1 | -0.00016 |
| | (0.00023) | | (0.00020) |
| F1: Weeks in D2 | -0.00004 | L1: Weeks in D2 | -0.00008 |
| | (0.00025) | | (0.00024) |
| F1: Weeks in D3 | -0.00020 | L1: Weeks in D3 | -0.00091*** |
| | (0.00027) | | (0.00026) |
| F1: Weeks in D4 | -0.00047 | L1: Weeks in D4 | -0.00174*** |
| | (0.00031) | | (0.00041) |
| L1: 1 Month of LFP | -0.01658 | F1: 1 Month of LFP | 0.00468 |
| | (0.01642) | | (0.01458) |
| L1: 3 Months of LFP | -0.00698 | F1: 3 Months of LFP | 0.00139 |
| | (0.01274) | | (0.01241) |
| L1: 4 Months of LFP | -0.01394 | F1: 4 Months of LFP | 0.00232 |
| | (0.01147) | | (0.00993) |
| L1: 5 Months of LFP | -0.00920 | F1: 5 Months of LFP | 0.01136 |
| | (0.01683) | | (0.01341) |
| F1:D2 x L1:1 LFP | 0.00112 | L1: D2 x F1:1 LFP | -0.00101 |
| | (0.00161) | | (0.00097) |
| F1:D3 x L1:3 LFP | 0.00256* | L1: D3 x F1: 3 LFP | -0.00167 |
| | (0.00134) | | (0.00116) |
| F1:D3 x L1:4 LFP | 0.00023 | L1: D3 x F1: 4 LFP | -0.00110 |
| | (0.00098) | | (0.00105) |
| F1:D4 x L1:4 LFP | 0.00037 | L1: D4 x F1: 4 LFP | 0.00034 |
| | (0.00187) | | (0.00101) |
| F1 D4 x L1:5 LFP | 0.00033 | L1: D4 x F1: 5 LFP | 0.00090 |
| | (0.00100) | | (0.00090) |
| L1: Unemployment | 0.00178 | L1: Unemployment | 0.00159 |
| | (0.00242) | | (0.00242) |
| L1: Irrigation | -0.00121** | L1: Irrigation | -0.00125** |
| | (0.00057) | | (0.00058) |
| Year Fixed Effects | Yes | Year Fixed Effects | Yes |
| County Fixed Effects | Yes | County Fixed Effects | Yes |
| Observations | 15,510 | Observations | 15,510 |
| Counties | 705 | Counties | 705 |
| Constant | 9.18788*** | Constant | 9.18764*** |
| | (0.01832) | | (0.01865) |
| $R^2$ (Within) | 0.08050 | $R^2$ (Within) | 0.08430 |
| $R^2$ (Between) | 0.03010 | $R^2$ (Between) | 0.01670 |
| $R^2$ (Overall) | 0.01160 | $R^2$ (Overall) | 0.00880 |
| F Statistic | 50.20 | F Statistic | 46.44 |

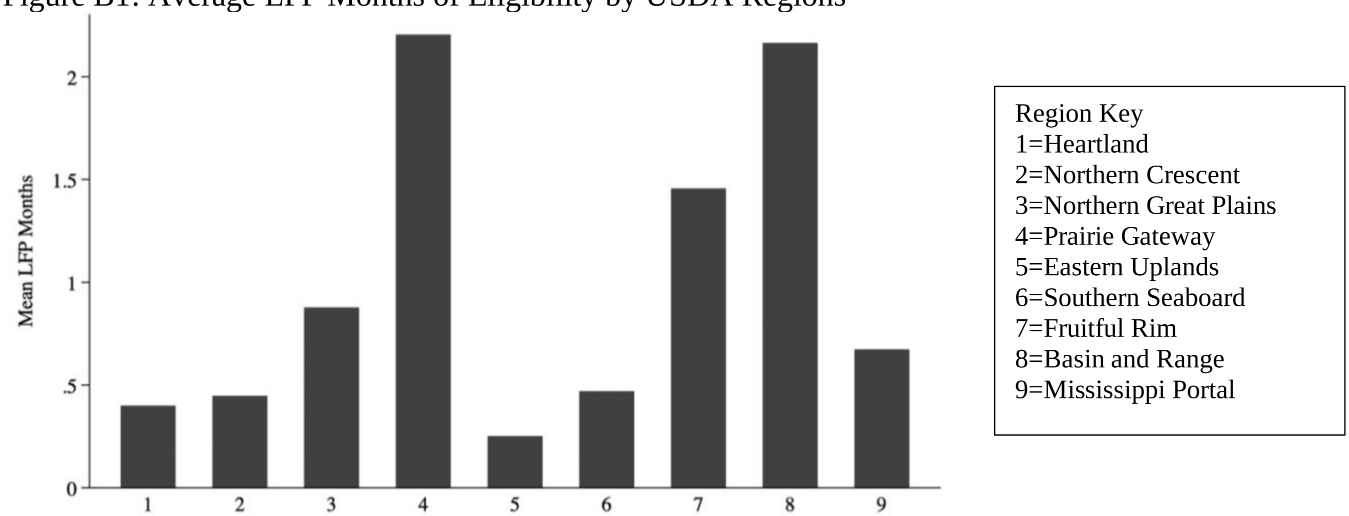
Notes: Standard errors clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

B. Extended Summary Statistics

Table B1: Summary Statistics for USDA Region Cattle Populations per County

| | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Heartland | 5,640 | 9,357 | 8,742 | 100 | 57,000 |
| Northern Crescent | 1,200 | 3,565 | 3,195 | 600 | 16,600 |
| Northern Great Plains | 1,392 | 26,072 | 19,229 | 1,500 | 103,000 |
| Prairie Gateway | 2,712 | 16,326 | 9,527 | 800 | 54,000 |
| Eastern Uplands | 3,528 | 17,831 | 11,033 | 900 | 62,000 |
| Southern Seaboard | 3,000 | 8,447 | 8,143 | 100 | 60,000 |
| Fruitful Rim | 2,520 | 14,217 | 13,452 | 400 | 88,000 |
| Basin & Range | 1,224 | 18,620 | 14,924 | 200 | 76,000 |
| Mississippi Portal | 1,536 | 6,200 | 5,173 | 100 | 30,000 |
| Total | 22,752 | 12,923 | 12,059 | 100 | 103,000 |

Figure B1: Average LFP Months of Eligibility by USDA Regions




Note on Regions: All region-specific specifications were tested but ultimately omitted due to limited observations, which yielded insufficient power to produce conclusive results.

Table B2: Summary Statistics

| Variable | Observations | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Cattle | 22,752 | 12,922.53 | 12,059.04 | 0 | 103,000 |
| Cum. Weeks in D0 | 22,752 | 9.54 | 7.790 | 0 | 52 |
| Cum. Weeks in D1 | 22,752 | 6.70 | 7.678 | 0 | 52 |
| Cum. Weeks in D2 | 22,752 | 4.53 | 7.576 | 0 | 52 |
| Cum. Weeks in D3 | 22,752 | 2.81 | 6.897 | 0 | 52 |
| Cum. Weeks in D4 | 22,752 | 1.21 | 5.216 | 0 | 52 |
| Cons. D0 or worse | 22,752 | 19.91 | 16.17 | 0 | 52 |
| Cons. D1 or worse | 22,752 | 13.07 | 15.34 | 0 | 52 |
| Cons. D2 or worse | 22,752 | 7.58 | 12.79 | 0 | 52 |
| Cons. D3 or worse | 22,752 | 3.61 | 9.08 | 0 | 52 |
| Cons. D4 | 22,752 | 1.11 | 4.90 | 0 | 52 |
| 1 LFP | 22,752 | 0.013 | 0.115 | 0 | 1 |
| 3 LFP | 22,752 | 0.019 | 0.138 | 0 | 1 |
| 4 LFP | 22,752 | 0.041 | 0.198 | 0 | 1 |
| 5 LFP | 22,752 | 0.025 | 0.156 | 0 | 1 |
| Irrigation (% of total Agriculture Land) | 16,920 | 20.59 | 17.72 | .18 | 90.46 |
| Unemployment rate (%) | 22,752 | 5.63 | 2.52 | .3 | 22.3 |