Drought Impacts on Cattle Industry in Intermountain West*

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Executive Summary

- Ranchers in the Intermountain West are dependent upon public rangeland to run their operations profitably. Availability of grazing on rain-fed public pasturelands is crucial for cattle ranchers, but the quality of grazing is negatively impacted by drought, which this region is susceptible to. As a result, drought displaces animals from the public range.

- Statistical models linking cattle inventory to drought conditions suggest that both temporary and sustained droughts have significant and negative impacts on the cattle industry in the region.

- A temporary drought (moderate/severe drought condition) results in a 1.44% to 2.17% decrease in cattle inventory and losses of $223 million to $335 million in sales in the region. If moderate/severe drought persists (sustained drought), the estimated losses in cattle inventory and sales are 3.76% to 5.64% and $583 million to $874 million, respectively.

- Changes (loss) in cattle inventory due to drought have effects on economies of the counties in the region. The direct effects of drought-related losses are changes in cattle inventory. Indirect effects of drought are changes in inter-industry purchases in response to different inventory levels. For example, lower cattle inventory impacts meat processing, wholesale sectors (downstream demanders) and feed and agricultural machinery, as well as other upstream inputs in rancher operations. The induced effect is the impact of household income changes and associated consumer expenditure as a result of changes in cattle inventory (direct effects) and inter-industry purchases (indirect effects).

- The estimated total *regional* economic impacts in Utah alone range from approximately $38.2 million in case of a temporary moderate drought to $89.8 million in the case of a sustained severe drought. Temporary drought is a drought which lasts one year and

reverts to normal condition and sustained drought is a drought which is persistent at least for three years. Moderate drought is defined with ΔPDSI $= -2$ and severe drought, ΔPDSI $= -3$.

Keywords: Cattle, Drought, Dynamic panel data model, Input-output analysis, Palmer Drought Severity Index

1. Introduction

Cattle ranching holds an important position within the agricultural sector in the Intermountain West region[1] and is considered essential for the livelihoods of ranchers in this region. For example, in the state of Utah, the cattle ranching is the dominant agricultural sector because it generates the highest sales value in the agricultural sector. In terms of share of agricultural sales, the cattle industry ranks first in Wyoming (65% of sales value), Colorado (53%), Montana (49%), Nevada (37%), and Utah (21%). Cattle sales rank second in New Mexico (24%) and third in Arizona (17%). In the period of 1990-2020, of the Intermountain West states, Colorado had the highest annual average cattle count (more than 2.8 million head), and Nevada the lowest (about 0.5 million head). More details regarding cattle sales and inventory (cattle including calves) are reported in Table 1. Further, lines Figure 1 shows changes in cattle inventory in each state in the period 1990-2020. Shaded areas on charts indicate the periods when the severe drought in each state occurred (more than 50% of the area in each state experienced the severe drought; many states had severe droughts in the periods of 2012-2014 and 2018-2019, as shown). It is not very clear to see, however, when the state experienced the severe drought, cattle inventory had moved downwards.

In this study, we hypothesize that the drought conditions have had a negative impact on the changes in the cattle inventory in Intermountain West as grazing on non-irrigated private and public lands is widely adopted in the region. First, these states are prone to drought. Wallander et al. (2013) evaluated drought risk in the U.S. on a county level using Palmer Modified Drought Index data over the past century, and a majority of the counties in the studied states have been assigned a moderate or highest drought risk. Further, the US Drought Montior (USDM) monitors drought in the U.S. on a weekly basis, and in the 2000-2019 period, there were weeks when 100% of the area was in severe drought or worse in each state, except Montana which had a maximum of 88% of the area in severe drought conditions. Averaging across weekly data in the 2000-2019 period and studied states, severe

[1] In this study, the Intermountain West includes 8 states, Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming.

Table 1: Cattle Industry in the Intermountain West in 2017

State	Total Ag. sales million $	Cattle and calf sales million $	Share of cattle and calf sales	Cattle incl. calves 1990-2020 (million head)		
				Average	Min	Max
Arizona	3,852	641	17%	0.905	0.810	1.020
Colorado	7,491	3,989	53%	2.827	2.300	3.250
Idaho	7,567	1,787	24%	2.065	1.660	2.500
Montana	3,521	1,716	49%	2.527	2.250	2.750
Nevada	666	247	37%	0.486	0.430	0.530
New Mexico	2,582	627	24%	1.489	1.300	1.640
Utah	1,839	378	21%	0.844	0.780	0.930
Wyoming	1,472	957	65%	1.379	1.190	1.660
Sub-total	28,990	10,342	36%			
US Total	388,523	77,189	20%	95.898	88.243	103.548

Sources: Ag Census 2017, NASS USDA

drought conditions or worse were observed on 27% of the area, ranging from 21% in Montana to 33% in Nevada (NIDIS, 2020).

Second, for livestock production, grazing on non-irrigated private and public lands is widely adopted in the region, and it is critical for the cattle industry, particularly in the case of young cattle grazing on public lands before being sent to feedlot operations. As reported by Glaser et al. (2015), the Bureau of Land Management (BLM) administers 175 million acres of federal lands outside of Alaska, and these are almost exclusively concentrated (99.8 %) in 11 western states[2] (in 2010)(see Figure 2 for public grazing allotment in the west). The US Forest Service (USFS) administers 142 million acres in these 11 western states, which account for 83 % of its total federal land holdings. According to the GAO (2005), livestock grazing is the prevailing use of BLM lands, with 138 million acres (79 % of the 175 million acres of BLM land in the West). The regions with the largest extent of USFS grazing lands are the Intermountain West region (Nevada, Utah and Idaho), the Southwest region (Arizona and New Mexico), and the Rocky Mountain region (Colorado, South Dakota, Kansas, Nebraska and Wyoming). With severe drought conditions, crop or

[2]The 11 western states are Arizona, California, Colorado, Idaho, Oregon, Montana, New Mexico, Nevada, Utah, Washington, and Wyoming.

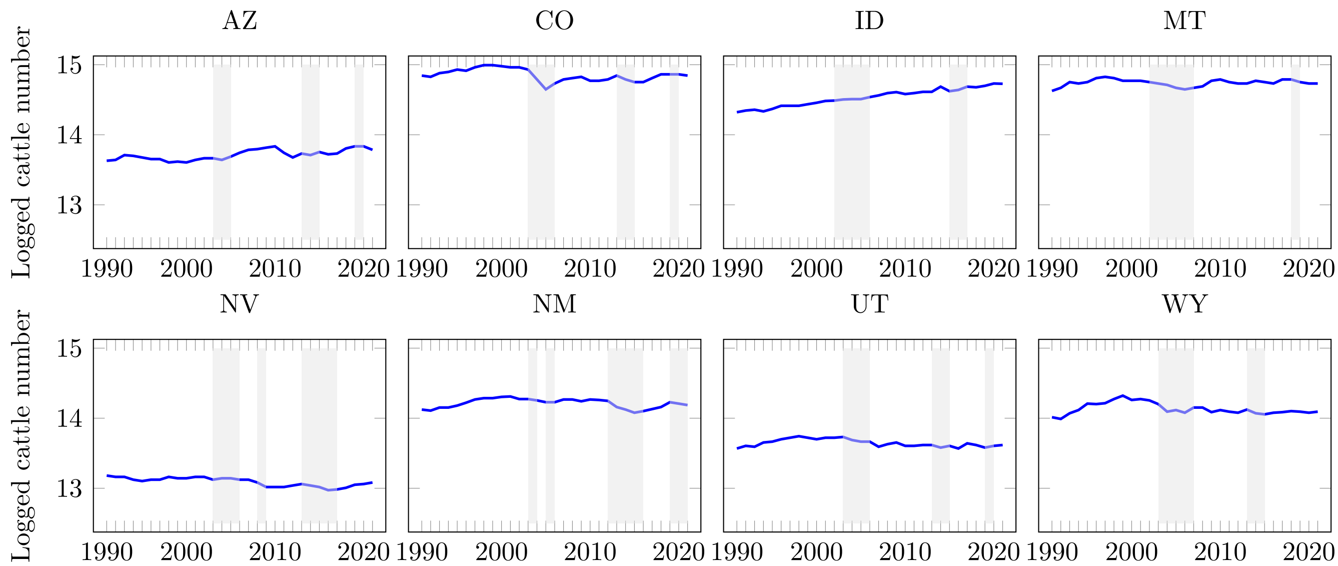

Figure 1: Cattle Inventory

y value of 13.2 ≈ 0.5 million head; 13.8 ≈ 1 million head; 14.5 ≈ 2 million head; shaded areas indicate the periods of drought.

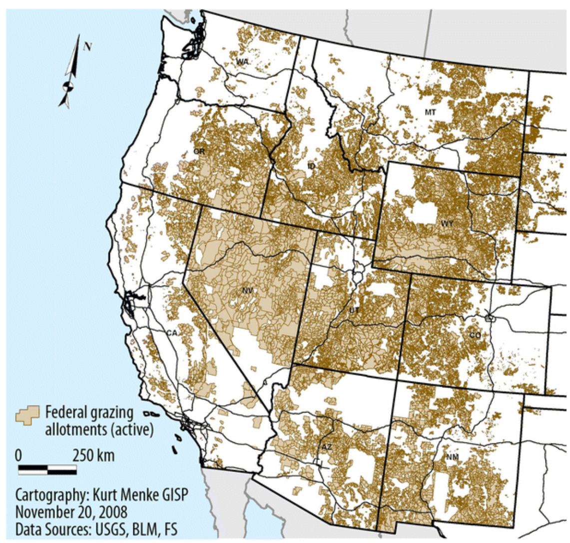

Figure 2: Public Grazing Allotment in the West

pasture losses are likely (NIDIS, 2020). Considering livestock production, drought negatively affects the availability and quality of rain-fed pastures and grazing land. If forage from these lands are not available in sufficient amounts and quality, cattle producers need to look for alternative feed sources or reduce their herd size. In addition, drought also reduces drinking water availability for livestock[3]. For this reason, the Pasture, Rangeland, and Forage (PRF)

[3]According to Holupchinski et al. (2018), there are short-term and long-term impacts from drought. Short-

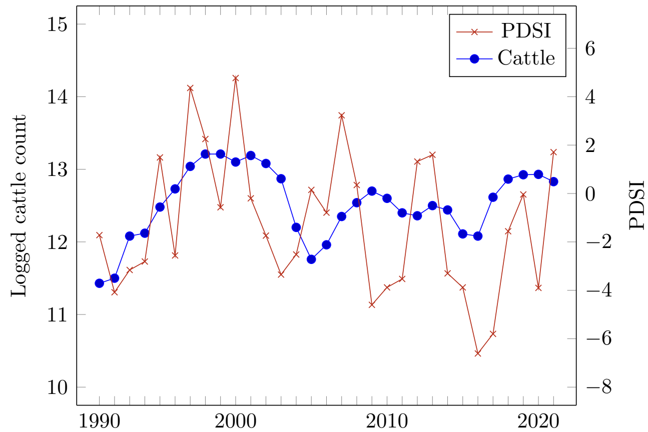

Figure 3: Cattle Inventory and PDSI in Intermountain West, 1990-2020

insurance program is designed to provide ranchers with financial support from poor grazing conditions caused by lack of precipitation (Van Orden et al., 2020).

In this study, we use Palmer Drought Severity Index (PDSI) as a drought indicator[4], and cattle counts on a county level to examine if and how droughts impacted cattle inventory in the Intermountain West states. Figure 3 shows the total cattle inventory in all eight states combined, and the yearly PDSI for the study region in the period of 1990-2020. PDSI data are compiled from National Climate Data Center (https://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp). Figure 3 suggests that there may be a relationship between the cattle inventory and drought. The simple correlation between cattle count and PDSI is 0.34 (P-value = 0.06), implying that drought may negatively affect the number of cattle on public lands.

term impacts include i) dry pastures lead to lower quality hay and increased fire danger, ii) decreases in feed availability can lead to overgrazing, iii) heat stress can decrease quality in beef, and iv) premature death leads to lower future yield. Long-term impacts include i) decreased water availability can lead to hay shortage, ii) nutrient poor, drought-tolerant grass species may spread which would decrease range quality and iii) purchased feed and need to re-sow overgrazed pastures.

[4]The PDSI is a measurement of dryness based on recent precipitation and temperature. The PDSI is an effective measure of long-term drought. A PDSI of 0 is normal; a negative PDSI indicates drought. For example, -2 is considered moderate drought, -3 indicates severe drought, and -4 is extreme drought. A positive PDSI indicates above-normal moisture. For example, +2 indicates moderate wetness, +3 severe wetness, and +4 is extreme wetness (Alley, 1984). We use PDSI in the study with two reasons. First, compared with other popular drought indices (e.g., SPEI), PDSI has a more comprehensive physical mechanism considering the balance of precipitation, evapotranspiration, and runoff and has the ability to assess local soil water and possibly vegetation properties (Trenberth et al., 2014). Second, PDSI is most effective in measuring impacts sensitive to soil moisture conditions in agriculture production (Fuchs, 2012).

2. Objectives

The goal of this research is to investigate the economic impact of drought on the cattle ranching industry in the Intermountain West. The four objectives of the research are:

(a) Determine if and how the drought has affected cattle inventories on a county level;

(b) Quantify the impact of drought on cattle inventories using county-level cattle and PDSI data;

(c) Estimate the economic impact of drought on the cattle industry in the study area; and

(d) Focusing on the state of Utah, estimate the state economic impacts from these changes.

3. Methodology

3.1. Drought-Cattle Model

To achieve the research objectives, the cattle inventory model in equation (1) was estimated. As we use the cattle inventory over time across counties, observed data have a panel structure, i.e., combining cross-sectional and time-series components. The panel data controls county-specific heterogeneity (characteristics) such as weather and soil quality, which is the beauty of the panel analysis. Time-series and cross-section studies not controlling this heterogeneity may obtain biased results (Baltagi, 2005). Also, the panel data are better able to identify and measure effects that are simply not detectable in cross-section or time-series data (Baltagi, 2005).

Cattle inventory is dynamic in nature. Ranchers' management decisions primarily relate to heifers and breeding cows because females are both a consumption good and a capital good (Rosen et al., 1994; Aadland and Bailey, 2001). Ranchers decide whether to retain heifers for their breeding stock or sell heifers for beef production. The decision for steers is simpler as they are consequently destined for slaughter because the number of males that need to be retained for breeding is small. Jarvis (1974) noted that ranchers have to retain some female calves in order to have the breeding stock necessary to produce calves or feeder cattle for the following year. As such, the total stock of female calves is proportional to the number of breeding cows in the previous period. As discussed, some heifers are retained for addition to the breeding stock and some are sent to market. The stock of retained yearling heifers, therefore, equals the fraction of heifers from the previous period that were not sent to market or did not die. In short the cattle inventory is dependent upon previous inventory. Adding a dynamic variable, lagged cattle inventory (last year's cattle inventory), to the panel model accounts for the dynamics (dynamic panel model)[5].

In addition, we assume drought to affect cattle inventory with a lag. In other words, cattle inventory responds not only to current drought condition but also to past drought conditions ; in other words, drought effects persist over time. The drought-cattle equation has two lagged PDSI in addition to the current PDSI since it takes anywhere from 2-3 years to bring beef from farm to the market. BSE dummy and trend variables are also added to the cattle inventory model; the following dynamic panel model is constructed in the analysis:

$$\begin{aligned} \ln Cattle_{c,s,t} = \beta_0 + \gamma \ln Cattle_{c,s,t-1} + \delta_0 PDSI_{c,s,t} + \delta_1 PDSI_{c,s,t-1} + \delta_2 PDSI_{c,s,t-2} \\ + \beta_1 BSE_t + \beta_2 Trend_t + u_{c,s} + \varepsilon_{c,s,t} \end{aligned} \quad (1)$$

where $\ln Cattle_{c,s,t}$ is natural logarithm of cattle number in county c, state s, and year t; $\ln Cattle_{c,s,t-1}$ is natural logarithm of cattle number in the previous year (lagged dependent variable); $PDSI$ is the value of PDSI (see the footnote 1 for more information). BSE is a dummy variable that equals 1 for the occurrence of BSE (years 2004 and 2005). Variables $u_{c,s}$ and $\varepsilon_{c,s,t}$ are time-invariant and time-variant components of the error terms, that are not explained by the drought-cattle model. Note that buying extra hay to sustain the herd or culling and selling more cattle than normal are the key decisions for ranchers when managing livestock during droughts with poor public grazing conditions. Unfortunately, we cannot observe county level hay prices, and thus must drop the hay price from the equation.

[5] Adding the lagged dependent variable to the right hand side of the panel model causes a problem because it is correlated with the error term, also known as the endogenous issue. In this case the standard panel data estimator is not consistent (Baltagi, 2005). A series of studies, for example, Arellano and Bond (1991); Arellano and Bover (1995); Blundell and Bond (1998), have suggested to how to overcome the endogenous problem caused by adding the lagged dependent variable and estimate the panel model efficiently. We follow suggestions from these studies.

3.2. Drought Impacts

This section will explain the interpretation of the coefficients, δ_0, δ_1, and δ_2, for PDSI and lagged PDSI in equation (1). Following Wooldridge (2013), suppose that PDSI is a constant (say it is close to normal conditions), equal to c in all time periods before t. At time t, suppose that PDSI decreases by one unit to $c-1$ (moving to drought conditions) and then reverts to its previous level at time $t+1$; that is, the decrease in PDSI is *temporary*. To focus on the ceteris paribus effect of PDSI on cattle inventory, we set the error terms and other variables in each time period to zero and suppress the subscripts c and s. Then

$$\begin{aligned}
\ln Cattle_{t-1} &= \delta_0 PDSI_{t-1} + \delta_1 PDSI_{t-2} + \delta_2 PDSI_{t-3} = \delta_0 c + \delta_1 c + \delta_2 c \\
\ln Cattle_{t} &= \delta_0 PDSI_{t} + \delta_1 PDSI_{t-1} + \delta_2 PDSI_{t-2} = \delta_0 (c-1) + \delta_1 c + \delta_2 c \\
\ln Cattle_{t+1} &= \delta_0 PDSI_{t+1} + \delta_1 PDSI_{t} + \delta_2 PDSI_{t-1} = \delta_0 c + \delta_1 (c-1) + \delta_2 c \\
\ln Cattle_{t+2} &= \delta_0 PDSI_{t+2} + \delta_1 PDSI_{t+1} + \delta_2 PDSI_{t} = \delta_0 c + \delta_1 c + \delta_2 (c-1) \\
\ln Cattle_{t+3} &= \delta_0 PDSI_{t+3} + \delta_1 PDSI_{t+2} + \delta_2 PDSI_{t+1} = \delta_0 c + \delta_1 c + \delta_2 c
\end{aligned} \tag{2}$$

and so on.

From the first two equations, $\ln Cattle_t - \ln Cattle_{t-1} = -\delta_0$, which shows the *immediate change* in cattle inventory due to the one-unit decrease in PDSI (moving to drought conditions) at time t. δ_0 is usually called the impact multiplier (Wooldridge, 2013). From the first and third equations, $\ln Cattle_{t+1} - \ln Cattle_t = -\delta_1$ is the change in cattle inventory one period after the temporary change. It implies that $\ln Cattle_{t+1} - \ln Cattle_t = -\delta_1 + \delta_0$ which is the marginal change in cattle inventory between the year and the year following the temporary drought. Similarly, $\ln Cattle_{t+2} - \ln Cattle_{t-1} = -\delta_2$ is the change two periods after the change and $\ln Cattle_{t+2} - \ln Cattle_{t+1} = -\delta_2 + \delta_1$ is the marginal change in cattle inventory in the second year after the temporary change. At time $t+3$, cattle inventory has reverted back to its initial level; that is, $\ln Cattle_{t+3} = \ln Cattle_{t-1} = 0$. In short, when PDSI decreases by one unit at time t, the drought effects persist for three years (t, $t+1$, and $t+2$). The (cumulative) short-run impact is

$$\text{Short-run impact } = -\delta_0 + (-\delta_1 + \delta_0) + (-\delta_2 + \delta_1) = -\delta_2 \tag{3}$$

We are interested in the changes in cattle inventory as a result of a *sustained* drought. Suppose that there is a decrease in PDSI and it lasts several years. In other words, before time t, PDSI equals c, at time t, PDSI decreases to $c-1$ (moving to drought) and stays at drought level. Again setting the errors and other variables to zero, we have

$$\begin{aligned}
\ln Cattle_{t-1} &= \delta_0 PDSI_{t-1} + \delta_1 PDSI_{t-2} + \delta_2 PDSI_{t-3} = \delta_0 c + \delta_1 c + \delta_2 c \\
\ln Cattle_{t} &= \delta_0 PDSI_{t} + \delta_1 PDSI_{t-1} + \delta_2 PDSI_{t-2} = \delta_0 (c-1) + \delta_1 c + \delta_2 c \\
\ln Cattle_{t+1} &= \beta_0 + \delta_0 PDSI_{t+1} + \delta_1 PDSI_{t} + \delta_2 PDSI_{t-1} \\
&= \delta_0 (c-1) + \delta_1 (c-1) + \delta_2 c \\
\ln Cattle_{t+2} &= \beta_0 + \delta_0 PDSI_{t+2} + \delta_1 PDSI_{t+1} + \delta_2 PDSI_{t} \\
&= \delta_0 (c-1) + \delta_1 (c-1) + \delta_2 (c-1)
\end{aligned} \tag{4}$$

and so on. With the change in PDSI, cattle inventory has changed by $-(\delta_0 + \delta_1)$ after one period and by $-(\delta_0+\delta_1+\delta_2)$ after two periods. This shows that the sum of the coefficients on current and lagged PDSI is the long-run change in cattle inventory. It is called the long-run multiplier (Wooldridge, 2013):

$$\text{Long-run impact } = -(\delta_0 + \delta_1 + \delta_2) \tag{5}$$

4. Data

For the empirical model in equation (1), county level data were collected for the period 2001-2016 and specifically, observed for 257 counties (eight Intermountain West states) over 16 years (total number of observations is 4,112). The drought is measured by PDSI which is collected on a monthly basis and county level. Yearly cattle (including calves) inventory data

Table 2: Overview of Variables and Summary Statistics

Variable	Definition	Mean	St.Dev.	Min	Max
cattle	Cattle count including calves	47,500	58,097	600	750,000
$\ln cattle$	Natural log of cattle count	10.26	1.04	6.40	13.53
$PDSI$	PDSI value	-1.11	2.17	-7.10	7.75

were collected on a county level from USDA National Agricultural Statistics Service (USDA NASS). In addition, occurrence of BSE were collected, which may negatively influence herd size. Table 2 presents the overview of the variables with summary statistics in the data.

5. Results

5.1. Cattle Inventory

Estimation results of equation (1) are reported in Table 3. Most of the parameters in Table 3 are statistically significant and have expected signs, that is, PDSI coefficients are positive, except the current PDSI term in Model 4. The estimates show that PDSI indeed affects the cattle inventory. All the estimates for the current and lagged PDSI are positive and statistically significant implying that drought conditions (decreases in PDSI values to negative) reduces cattle inventories. In addition, effects of drought persist over time (lagged effects).

Model 1 in Table 3 reports the estimation results with all counties in the data. As shown in Table 3, the immediate impact is 0.0049–the cattle inventory decreases by 0.49% when PDSI decreases by one unit[6]. One period after the *temporary* change in PDSI, the cumulative decrease in cattle inventory is 0.67% and two periods after, 0.72%, which is the short-run impact (equation 3). If the drought is persistent in the region, we would expect that cattle inventory decreases by 1.88% (long-run impact, equation 5) when PDSI decreases

[6]In the log-linear (semi-log) setup, coefficients for the current and lagged PDSI measures the relative change in cattle inventory for a given absolute change in PDSI, or

$$\delta = \frac{d\ln Cattle}{dPDSI} = \frac{dCattle/Cattle}{dPDSI}.$$

Thus, 100 times δ gives the percentage change in cattle inventory.

Table 3: Dynamic Panel Estimation Results (Dependent Variable: $\ln Cattle_t$)

	Model 1 All counties	Model 2 Counties with < 15600 head	Model 3 Counties with 15600 & 30500 head	Model 4 Counties with 30500 & 57000	Model 5 Counties with > 57000 head
$\ln Cattle_{t-1}$	0.716***	0.441***	0.191***	0.229***	0.558***
	(0.006)	(0.004)	(0.004)	(0.005)	(0.006)
$PDSI_t$	0.0049***	0.0058***	0.0043***	−0.0017***	0.0005***
	(0.0004)	(0.0004)	(0.0002)	(0.0003)	(0.0002)
$PDSI_{t-1}$	0.0067***	0.0040***	0.0041***	0.0029***	−0.0001
	(0.0003)	(0.0003)	(0.0002)	(0.0002)	(0.0002)
$PDSI_{t-2}$	0.0072***	0.0121***	0.0057***	0.0041***	0.0065***
	(0.0003)	(0.0003)	(0.0002)	(0.0003)	(0.0002)
BSE	−0.003	−0.010***	−0.036***	−0.016***	−0.017***
	(0.002)	(0.003)	(0.001)	(0.002)	(0.002)
$Trend$	0.0002	−0.001***	−0.003***	−0.002***	−0.0003
	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.002)
Constant	2.936***	5.01***	8.154***	8.230***	5.105***
	(0.057)	(0.037)	(0.043)	(0.050)	(0.067)
Number of obs.	3,855	926	900	895	877
Number of counties	257	81	97	94	77
Arellano-Bond test[1]					
Order 1	-8.38 [0.00]	-4.84 [0.00]	-4.44 [0.00]	-4.79 [0.00]	-5.97 [0.00]
Order 2	1.28 [0.20]	0.73 [0.48]	0.33 [0.74]	-1.02 [0.31]	1.23 [0.22]
Sargan's J test[2]	246.3 [0.00]	78.19 [1.00]	92.71 [0.96]	91.65 [0.97]	73.93 [1.00]

Standard errors are reported in parentheses; *, **, *** indicate the significance at 10%, 5% and 1%, respectively.

[1] Arellano and Bond test statistics (Arellano and Bond, 1991) with a p-value in the bracket. Arellano-Bond test is testing for zero autocorrelation in first-differenced errors. By construction, the first-differenced errors are first-order serially correlated, i.e., order 1 should be rejected. Arellano-Bond test fails to reject the serial correlation with order 2 and it indicates that the moment conditions used in estimation are valid.

[2] Sargan's J test statistics (Sargan, 1958; Hansen, 1982) with a p-value in the bracket. Sargan test rejects the null hypothesis that model and overidentifying conditions are correct, which was not expected. However, Arellano and Bond (1991) show that Sargan test overrejects in the presence of heteroskedasticity. Combining various size of counties could suffer from heteroskedasticity problem. Note that dividing counties (models 2-5) makes counties more homogeneous and it mitigates the heteroskedasticity problem (fail to reject Sargan test).

by one unit and it persists.

Counties are further segmented into four groups by their percentiles in terms of cattle count. For example, counties with less than 15,600 cattle fall on the 25th percentile. This enables us to observe if there exists any different impacts of drought on cattle inventory. We

Table 4: Loss in Cattle Inventory in Percent due to Drought when $\Delta PDSI = -1$

	Model 1 All counties	Model 2 Counties with < 15600 head	Model 3 Counties with 15600 & 30500 head	Model 4 Counties with 30500 & 57000	Model 5 Counties with > 57000 head
Short-run impact	0.72	1.21	0.57	0.41	0.65
(%)	[0.66, 0.79]	[1.16, 1.27]	[0.54, 0.60]	[0.35, 0.46]	[0.61, 0.69]
Long-run impact	1.88	2.20	1.40	0.53	0.69
(%)	[1.77, 1.99]	[2.11, 2.29]	[1.34, 1.47]	[0.41, 0.65]	[0.64, 0.75]

hypothesized that the smaller counties are more sensitive to drought. As expected, smaller counties are more sensitive to drought. For example, the long-run impact of drought is estimated to be 2.2% for the lower 25th percentile counties (counties with less than 15,600 cattle head). For the lower 50th percentile counties (counties with cattle between 15,600 head 30,500 head), it is estimated to be 1.4%, and for top percentile counties it becomes 0.5% ∼ 0.7%. Table 4 reports the summary of drought impact. As shown in Table 4 smaller counties (in terms of cattle inventory) are more vulnerable to drought. Also, larger counties (Models 4 and 5) are resilient to sustained drought since short-term impact is statistically similar to long-term impact.

5.2. Direct Impact of Drought on Cattle Industry

Using the estimates for Model 1 reported in Tables 3 and 4, the loss in cattle inventory and sales due to drought are computed. Suppose that PDSI decreases by *two units* from normal conditions, that is, moving to *moderate* drought, and then reverts to normal conditions (*temporary moderate drought*). We expect that cattle inventory decreases by 0.98% immediately, an additional 0.36% after one year, and 0.1% more after two years (see equations 2 and 3)[7]. Figure 4 demonstrates the changes in cattle inventory due to the temporary moderate

[7] Following equations 2, when PDSI decreases by two units at time t, $\ln Cattle_t - \ln Cattle_{t-1} = -2\delta_0$ is the immediate change in cattle inventory; $\ln Cattle_{t+1} - \ln Cattle_{t-1} = -2\delta_1$ is the total change in cattle inventory one period after the temporary change. It implies that $\ln Cattle_{t+1} - \ln Cattle_{t} = -2\delta_1 + 2\delta_0$ is the marginal change in cattle inventory between the year following the temporary change and t when the drought occurs. Similarly, $\ln Cattle_{t+2} - \ln Cattle_{t+1} = -2\delta_2 + 2\delta_1$ is the marginal change in cattle inventory in the second year after the temporary change. The short-run impact is $-2\delta_2$.

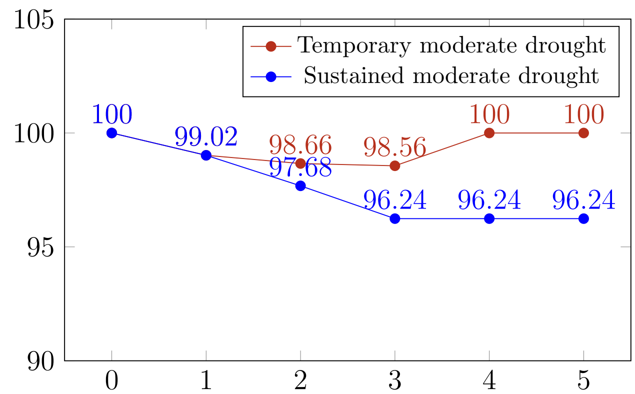

Figure 4: Impacts of Moderate Drought on Cattle Inventory

drought. Suppose that the initial cattle inventory is 100 and the moderate drought occurs when $t = 1$. As shown in Figure 4, the cattle number decreases to 99.02 immediately, to 98.66 at time $t = 2$ and to 98.56 at time $t = 3$. Cattle count reverts back to 100 when $t = 4$ as the drought ends.

What if drought is sustained? As shown in Table 4, the long-run impact is estimated to be 1.88% for Model 1. If the region experiences moderate drought (two-unit decreases in PDSI) and it is persistent, there exist *permanent* decreases in cattle inventory by 3.76% (= 1.88%×2). Figure 4 also demonstrates the sustained moderate drought case.

Direct economic losses of drought on cattle inventory in the Intermountain West are calculated using the short-run and long-run impacts in Table 4, the cattle inventory in the Intermountain West in 2017, 12.865 million head and the value of cattle in 2017 (average of eight Intermountain West states), $1,204/head. Table 5 contains the results with temporary/sustained and moderate/severe droughts.

6. Economic Impact of Drought in Utah

6.1. Supply Driven SAM Analysis

Changes (loss) in cattle inventory due to drought have effects on the regional economies of the states. This research utilizes the Input-Output framework using IMPLAN (IMpact analysis for PLANning) database to measure the regional economic impact from changes in cattle inventory in Utah. The direct effects of drought-related losses are the changes in cattle inventory (in dollar value reported in Table 5). Indirect effects of drought are the changes in inter-industry (input suppliers for cattle ranchers and industries buying cattle from ranchers) purchases as they respond to different inventory levels. For example, lower cattle inventory impacts feed and agricultural machinery, as well as other upstream inputs in rancher operations, and meat processing, wholesale sectors (downstream demanders). The induced effect is the impact of household income changes and associated consumer expenditure as a result of changes in cattle inventory (direct effects) and inter-industry purchases (indirect effects). This type of approach is called *demand-driven IO model* because this approach assumes that the change in cattle inventory is the exogenous change in final demand in the regional economy.

Other studies, such as those by Leung and Pooley (2002); Seung and Waters (2009); Kim (2015); Kim et al. (2017), have argued that a supply-driven IO model is more appropriate than a demand-driven IO model in situations where the output level is altered directly from a supply-side shock such as drought. That is, in a supply-driven IO model a supply reduction may occur rather than having a shock resulting from a shift in the demand curve. This is important because the supply effects are easier to estimate than the immediate

Table 5: Economic Loss in Cattle Industry in Intermountain West due to Drought

Scenario at t		% change (percent)	Cattle[1] (million head)	Cattle Sales[2] (million $)	% of Cattle Sales in 2017
Temporary drought	Moderate	1.44	0.186	223	2.16%
	$\Delta PDSI = -2$	[1.32, 1.58]	[0.169, 0.203]	[215, 257]	
	Severe	2.17	0.279	335	3.25%
	$\Delta PDSI = -3$	[1.97, 2.36]	[0.254, 0.304]	[306, 366]	
Sustained drought	Moderate	3.76	0.484	583	5.96%
	$\Delta PDSI = -2$	[3.55, 3.98]	[0.456, 0.512]	[549, 617]	
	Severe	5.64	0.726	874	8.94%
	$\Delta PDSI = -3$	[5.32, 5.97]	[0.684, 0.768]	[823, 925]	

Numbers in brackets are 95% confidence intervals.
[1] Cattle inventory in 2017 in Intermountain West (12.865 million head) × % change
[2] Value per head in 2017 (average of 8 states) = $1,204/cattle (source: Table 7-3 USDA NASS, 2018 Agricultural Statistics)

demand effects because the change in (final) demand is unknown. Using supply-driven IO multipliers, we can calculate both the backward and forward linkage effects of drought and cattle inventory changes. The backward linkage is a sector's relationship to upstream sectors (suppliers) that provide goods and services to cattle ranching & farming sector (Seung and Waters, 2009), e.g., the reduction in cattle herd size may reduce demand for inputs purchased from other sectors such as labor, feed, manufactured items (e.g., agricultural machinery, fencing, water infrastructure), and support services, such as those supplied by veterinarians, banks, insurance agencies, etc. The forward linkages are a sector's relationships with downstream demand for goods and services from the cattle ranching & farming sector (Seung and Waters, 2009) e.g., changes in cattle inventory may also reduce the output of meat processing company (manufacturing sector) and wholesale sectors that purchase inputs from the cattle ranching sector[8].

In this study we attempt to measure the state level economic impacts of drought. We construct Utah's economy, aggregating over 480 economic sectors into 10 aggregate sectors based on the IMPLAN database for the year 2017. While most of these sectors are highly aggregated, we maintain cattle ranching and farming as a separate, though smaller, economic sector. Before modeling the effect of drought, the gross regional product in Utah was $168 billion and this level of economic activity supported an estimated 1.97 million jobs. The cattle ranching & farming sector produced $498 million and supported 5,923 jobs in Utah in 2017.

6.2. Estimating Direct Economic Loss due to Drought in Utah

Using the estimates reported in Tables 3 and 4, and 2017 cattle number in each county, we may calculate the direct economic loss due to drought. Cattle inventory in 2017 and the percent loss in cattle inventory by county and percentiles in the Intermountain West are reported in Table 6. Direct impacts with temporary/sustained moderate/severe droughts

[8]Derivation of supply-driven IO or Social Accounting Matrix (SAM) multipliers is beyond the scope of this research. Refer to Kim (2015) for the supply-driven IO model and to Kim et al. (2017) for the supply-driven SAM model.

Table 6: Cattle Inventory in Utah Counties in 2017, Percentiles in Intermountain West, and % Loss in Cattle due to Drought

Ag District	County	Cattle Inventory[1] (head)	Percentiles	% Loss in Cattle[2] (%) Short-run impact	Long-run impact
Northern	Box Elder	90,000	4	0.65	0.69
	Cache	55,000	3	0.41	0.53
	Davis	3,400	1	1.21	2.20
	Morgan	7,900	1	1.21	2.20
	Rich	47,000	3	0.41	0.53
	Salt Lake	3,200	1	1.21	2.20
	Tooele	23,500	2	0.57	1.40
	Weber	21,000	2	0.57	1.40
Central	Juab	18,300	2	0.57	1.40
	Millard	75,000	4	0.65	0.69
	Sanpete	52,000	3	0.41	0.53
	Sevier	49,000	3	0.41	0.53
	Utah	62,000	4	0.65	0.69
Eastern	Carbon	11,200	1	1.21	2.20
	Daggett	2,800	1	1.21	2.20
	Duchesne	49,500	3	0.41	0.53
	Emery	26,500	2	0.57	1.40
	Grand	3,600	1	1.21	2.20
	San Juan	15,100	1	1.21	2.20
	Summit	15,200	1	1.21	2.20
	Uintah	38,000	3	0.41	0.53
	Wasatch	10,000	1	1.21	2.20
Southern	Beaver	22,500	2	0.57	1.40
	Garfield	18,700	2	0.57	1.40
	Iron	43,500	3	0.41	0.53
	Kane	8,700	1	1.21	2.20
	Piute	15,200	1	1.21	2.20
	Washington	15,300	1	1.21	2.20
	Wayne	17,900	2	0.57	1.40
Sum		821,000			

[1] Source: 2018 Annual Summary Report (Utah Department of Agriculture & Food)
[2] Tables 3 and 4

are reported in Table 7. In summary, temporary drought may cause the loss of $12 million to $18 million in sales (2.4% to 3.6% of 2017 Utah cattle sales) and sustained drought may cause the loss of $19 million to $28 million (3.8% to 5.7% of 2017 Utah cattle sales).

6.3. Economic Impacts of Drought in Utah

State economic impacts for temporary/sustained moderate/severe droughts are reported in Tables 8 and 9. Impact on related industries, and value added (e.g., labor income, other property income, and indirect business taxes) are estimated to be $26.3 million when Utah ex-

Table 7: Economic Loss due to Drought in Utah

County	Temporal Drought				Sustained Drought			
	Loss in Cattle		Loss in Cattle Sales[1]		Loss in Cattle		Loss in Cattle Sales[1]	
	Moderate	Severe	Moderate	Severe	Moderate	Severe	Moderate	Severe
	(head)		(million $)		(head)		(million $)	
Box Elder	1,174	1,760	1.385	2.077	1,249	1,874	1.474	2.211
Cache	446	668	0.526	0.789	581	871	0.685	1.028
Davis	82	124	0.097	0.146	150	224	0.177	0.265
Morgan	192	287	0.226	0.339	348	521	0.410	0.615
Rich	381	571	0.449	0.674	496	744	0.586	0.878
Salt Lake	78	116	0.092	0.137	141	211	0.166	0.249
Tooele	267	401	0.316	0.473	660	990	0.779	1.168
Weber	239	358	0.282	0.423	590	885	0.696	1.044
Juab	208	312	0.246	0.369	514	771	0.606	0.910
Millard	978	1,467	1.154	1.731	1,041	1,562	1.228	1.843
Sanpete	421	632	0.497	0.746	549	824	0.648	0.972
Sevier	397	595	0.468	0.703	517	776	0.611	0.916
Utah	808	1,213	0.954	1.431	861	1,291	1.015	1.523
Carbon	272	408	0.321	0.481	493	739	0.582	0.872
Daggett	68	102	0.080	0.120	123	185	0.145	0.218
Duchesne	401	601	0.473	0.710	523	784	0.617	0.925
Emery	302	452	0.356	0.534	744	1,116	0.878	1.317
Grand	87	131	0.103	0.155	158	238	0.187	0.280
San Juan	366	549	0.432	0.648	664	997	0.784	1.176
Summit	369	553	0.435	0.653	669	1,003	0.789	1.184
Uintah	308	462	0.363	0.545	401	602	0.474	0.710
Wasatch	243	364	0.286	0.429	440	660	0.519	0.779
Beaver	256	384	0.302	0.453	632	948	0.746	1.118
Garfield	213	319	0.251	0.377	525	788	0.620	0.929
Iron	352	529	0.416	0.624	459	689	0.542	0.813
Kane	211	317	0.249	0.374	383	574	0.452	0.678
Piute	369	553	0.435	0.653	669	1,003	0.789	1.184
Washington	371	557	0.438	0.657	673	1,010	0.794	1.192
Wayne	204	306	0.240	0.361	503	754	0.593	0.890
Sum	10,062	15,093	11.87	17.81	15,755	23,633	18.59	27.89
% of 2017 inventory or sales[2]	1.23%	1.84%	2.42%	3.63%	1.92%	2.88%	3.79%	5.69%

[1] Value per head in 2017 = $1,180 (source: Table 7-3 USDA NASS, 2018 Agricultural Statistics)
[2] Value of sales in 2017 is $490 million (source: page 31 Utah Annual Bulletin, 2018, USDA NASS)

periences a temporary moderate drought and $39.5 million when a temporary severe drought, respectively. Backward (suppliers to cattle ranching sectors) impact is $20.4 million with a temporary moderate drought ($30.5 million with a temporary severe drought) and forward (demanders from cattle ranching sector) impact is $6 million ($9 million). Impact on household income and government revenue are estimated to be $8 million ($12 million). Total regional economic impacts are given by $38.2 million ($57.3 million) (Table 8).

Table 8: Economic Impact of *Temporary* Drought in Utah

	Temporary moderate drought			Temporary severe drought		
Sectors	Backward[1]	Forward[2]	Total	Backward	Forward	Total
Impact on industries (Indirect)	7.23	4.81	12.03	10.84	7.21	18.06
Other agriculture, forestry, fish	0.16	0.02	0.17	0.24	0.02	0.26
Grain farming	0.00	0.00	0.00	0.00	0.00	0.00
Mining	0.02	0.02	0.04	0.03	0.03	0.06
Utilities	0.21	0.00	0.22	0.32	0.01	0.33
Construction	0.22	0.09	0.31	0.32	0.14	0.47
Manufacturing	0.71	4.02	4.74	1.07	6.04	7.11
Wholesale	0.46	0.03	0.49	0.69	0.05	0.74
Retail	0.36	0.06	0.42	0.54	0.09	0.62
Transportation	0.39	0.04	0.43	0.59	0.06	0.65
FIRE[3]	2.66	0.18	2.84	3.99	0.28	4.26
Other services	1.43	0.24	1.67	2.15	0.36	2.51
Government	0.61	0.09	0.70	0.91	0.13	1.04
Impact on VA (Indirect)	7.50	0.46	7.96	11.25	0.69	11.94
Employment compensation	2.83	0.32	3.15	4.24	0.48	4.72
Proprietary income	0.05	0.03	0.08	0.07	0.05	0.12
Other property income	4.09	0.07	4.16	6.13	0.11	6.24
Indirect business taxes (IBT)	0.54	0.04	0.58	0.81	0.06	0.87
Impacts on HH income (Induced)	4.11	0.51	4.62	6.17	0.76	6.93
Low income HH (upto 35k)	0.41	0.09	0.50	0.61	0.14	0.75
Medium income HH (35k to 100k)	2.14	0.27	2.41	3.21	0.41	3.62
High income HH (over 100k)	1.56	0.14	1.70	2.34	0.21	2.56
State revenue (Induced)	1.52	0.21	1.72	2.28	0.31	2.59
Indirect+induced	20.35	5.98	**26.34**	30.54	8.98	**39.52**
Total regional impact			**38.21**			**57.33**

Unit: million dollars
[1] Backward linkage is a sector's relationship with upstream sectors (suppliers) that provide goods and services used as intermediate inputs in cattle ranching,
[2] Forward linkages as a sector's relationship with its downstream demanders who purchase cattle from cattle ranching sector.
[3] Finance, Insurance, Real estate, and Education

In case of sustained drought, the regional economic impacts are estimated in Table 9. Total state economic impacts are $59.8 million when Utah experiences a sustained moderate drought and $89.8 million when the state experiences a sustained severe drought.

7. Summary

This study examined the direct impact of drought on cattle inventory and sales in the Intermountain West region. Further, we estimated the overall economic impact of the reduced cattle inventory and sales due to drought in Utah. The results showed that a change from normal conditions to drought, lasting one year or longer, has significant and negative impacts

Table 9: Economic Impact of *Sustained* Drought in Utah

Sectors	Sustained moderate drought Backward[1]	Forward[2]	Total	Sustained severe drought Backward	Forward	Total
Impact on industries (Indirect)	11.32	7.53	18.85	16.98	11.29	28.28
Other agriculture, forestry, fish	0.25	0.02	0.27	0.37	0.04	0.41
Grain farming	0.00	0.00	0.00	0.00	0.00	0.00
Mining	0.03	0.03	0.06	0.05	0.05	0.10
Utilities	0.33	0.01	0.34	0.49	0.02	0.51
Construction	0.34	0.15	0.49	0.51	0.22	0.73
Manufacturing	1.12	6.30	7.42	1.67	9.46	11.13
Wholesale	0.72	0.05	0.77	1.08	0.08	1.16
Retail	0.56	0.09	0.65	0.84	0.13	0.98
Transportation	0.61	0.06	0.68	0.92	0.09	1.02
FIRE[3]	4.16	0.29	4.45	6.24	0.43	6.68
Other services	2.25	0.38	2.62	3.37	0.56	3.93
Government	0.95	0.14	1.09	1.43	0.21	1.64
Impact on VA (Indirect)	11.74	0.72	12.47	17.62	1.09	18.71
Employment compensation	4.43	0.50	4.93	6.64	0.75	7.39
Proprietary income	0.07	0.05	0.13	0.11	0.08	0.19
Other property income	6.40	0.11	6.51	9.61	0.17	9.77
Indirect business taxes (IBT)	0.84	0.06	0.90	1.26	0.09	1.36
Impacts on HH income (Induced)	6.44	0.80	7.23	9.66	1.19	10.85
Low income HH (upto 35k)	0.64	0.15	0.79	0.96	0.22	1.18
Medium income HH (35k to 100k)	3.35	0.42	3.78	5.03	0.64	5.67
High income HH (over 100k)	2.45	0.22	2.67	3.67	0.34	4.00
State revenue (Induced)	2.38	0.32	2.70	3.57	0.48	4.05
Indirect+induced	31.88	9.37	**41.25**	47.83	14.06	**61.88**
Total regional impact			**59.84**			**89.77**

Unit: million dollars

[1] Backward linkage is a sector's relationship with upstream sectors (suppliers) that provide goods and services used as intermediate inputs in cattle ranching,

[2] Forward linkages as a sector's relationship with its downstream demanders who purchase cattle from cattle ranching sector.

[3] Finance, Insurance, Real estate, and Education

on the cattle inventory and sales in the Intermountain West region, and overall economy, which was examined in Utah.

Drought impacts are initially experiences as negative impacts on the quality and availability of grazing on rain-fed pasturelands, which cattle ranchers in the drought-prone Intermountain West region rely on for raising young cattle. Reduced grazing quality and availability leads ranchers to either use other sources of feed, such as hay, of which production may suffer from the drought as well, resulting in higher hay prices, or decide to reduce calf breeding in an effort to curb production costs increase. Reduction of calf breeding will impact cattle production throughout the entire cattle industry, as fewer cattle will be sent to feedlots and be available for slaughter later on, or for the production of milk. Reduced cattle inventory also implies smaller purchases of inputs necessary for cattle production (e.g. grains, veterinary services, equipment) and less output sold to food manufacturers and retailers, resulting in ripple effects throughout the entire economy, not limited to the cattle industry alone.

In conclusion, the findings of this study highlight a need for measures that would prevent cattle ranchers from cost of drought. Currently, the Pasture, Rangeland, Forage (PRF) insurance program is available to compensate producers for the forage losses due to the reduced precipitation in a specific time interval only, however, it does not protect them from a sustained, multi-year droughts. It is because, as discussed in Willis (2019), PRF indemnities are tied solely to a deviation from normal precipitation for the two-month intervals insured. Additionally, since the program only requires that two intervals be insured, a rancher may choose to only insure for four months of the year. As indicated in Van Orden et al. (2020), many ranchers in the Intermountain West are reluctant to utilize the PRF insurance program, expressing concern over a lack of payouts during periods of poor forage availability. These concerns, if accurate, suggest that the PRF program may not always achieve the goal of helping to cover the replacement cost of feed during times of poor forage conditions. The large overall economic impacts estimated in Utah in this study indicate a need to reconsider the current conditions of the PRF insurance program.

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