The Spatio-temporal Impact of Drought on Local and Regional Feeder Cattle Inventories

Eric J. Belasco
Assistant Professor
Department of Agricultural Economics and Economics
Montana State University
eric.belasco@montana.edu


Copyright 2013 by Belasco. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.
The Spatio-temporal Impact of Drought on Local and Regional Feeder Cattle Inventories

Abstract:
Recent droughts have demonstrated the sensitivity of cattle inventories to adverse weather. State-level first-differenced panel regressions are used to estimate the impact of drought conditions on rancher decisions regarding herd size. Results provide insights into the recovery time associated with and degree of rebuilding cattle herds following a drought. Regional cattle inventory responses to weather are shown to be asymmetric as drought conditions have substantial short-run impacts on inventory which are difficult to rebuild.

Keywords: cattle, drought, inventory.
The Spatio-temporal Impact of Drought on Local and Regional Feeder Cattle Inventories

Agricultural production holds a unique position in the U.S. economy in the way that risk enters into production. Risks in the form of price and production uncertainty are often managed through more robust inputs (e.g., seed varieties, livestock genetics), more adaptable production practices, as well as price insurance through futures/options and public/private insurance markets. In times of drought, cattle producers are provided substantial economic incentives to move local cattle inventories to areas with more available forage, utilize higher cull rates, and place feeder cattle in feedlots at an earlier age. These decisions have lasting impacts on beef cattle herd inventory as there is typically a two-year lag between birth and slaughter or breeding. The availability of local pasture is an essential input for cow-calf producers to maintain some inventory of cattle. For this reason, changes in cattle inventories can be sensitive to evolving drought conditions. The degree to which this shock has a temporal and/or long-term impact on local inventories largely depends on the response to upside and downside shocks to local forage production and cattle prices. This is substantially different than in crop production, where a drought is likely to impact crop production for a single year while the adverse impacts on income can be mitigated through irrigation or crop insurance. In contrast, many cow-calf operations rely on the long-term health and vitality of forage.

Recent droughts have demonstrated the importance of good pasture and rangeland in maintaining cattle inventory numbers. In the summer of 2011, the Southern High Plains experienced a one-hundred year drought where 64% of the rangeland was rated as “very poor” based on the NASS rating system detrended hay production fell by 59% from the prior year. This drought year was followed by a drastic 13% reduction in cattle inventory in 2012. This reduction in inventory came as animals were sold at lighter weights than normal and shipped to regions with available forage.
grass, in spite of hay being purchased from as far away as Montana (Billings Gazette, 2011). A prolonged drought is believed to have an even larger impact in next year’s cattle inventory. This research examines the expected regional response path with regard to potential herd rebuilding or continued reductions in response to drought. Using the window of the last 10 years brings into focus the severe droughts in 2007 (South) and 2002 (Central High Plains), among others. Conditions during the late summer of 2012 are indicating that the Northern High Plains may be impacted by drought conditions more substantially than the drought during 2000-2003. A severe drought in the Midwest during the mid-1990s also resulted in extremely high livestock mortality rates. Given the spread in cow-calf operations across the United States, a serious drought in the U.S. becomes very likely to impact some portion of the beef cow industry. We hypothesize that this patchwork of droughts across the US helps partially explain the longer term declines in cattle inventories that began in 1975.

Many studies have focused on the impacts from drought conditions on crop yields (Nelson et al., 2009; Schlenker and Roberts, 2009), while very few research studies have focused on the impact on the livestock industry (Antle and Capalbo, 2010). Past efforts regarding the response of ranchers to drought conditions have treated cattle inventories as capital goods, where the optimal herd size is a function of local grain availability and national prices (Jarvis, 1974; Rosen et al., 1994; Rucker et al., 1984; Schmitz, 1997; Trapp, 1986). More recent efforts have focused on the impact of competing drought mitigation strategies (Bastian et al., 2006; Ritten et al., 2010) and the risk associated with different stocking rates (Parsch et al., 1997).

This research focuses on two gaps in the literature. First, much of the research has focused on the time series component of cattle inventories by focusing on a national or single state. This research draws on a rich cross-sectional data by utilizing state level data. Because of this, we are able to focus on local drought conditions with local variation which provides a more accurate characterization of ranch-level choices in response to weather outcomes. Second, this research focuses on both the immediate response to drought conditions as well as the longer term response in terms
of rebuilding the herd back to pre-drought inventory. This asymmetric relationship between building herds in times of plentiful forage and reducing herds in times of limited forage may provide a partial link regarding the steady declines in cattle inventories since 1975. Given these gaps in research, this research provides important and timely information with regard to the potential impact drought has on livestock supplies. While drought conditions can also impact more mature feeder cattle in the form of higher cost of feed grains and lower productive performance, feeder calves are more sensitive to drought conditions with higher mortality rates, more drastic impacts on production, and added mobility. For these reasons, this study focuses on the cow-calf production sector, which is especially reliant on decent weather.

**Theoretical Framework**

Rancher decisions regarding the optimal herd size are importantly related to current and future expectations regarding profitability, which importantly relies on the availability of feed and output prices. The supply of beef cow-calf inventory is comprised of breeding stock, calves, and heifers. Calves are generally defined as being less than a year old or less than 500 pounds. Once calves are weaned, most animals are sent to backgrounding operations or feedlots. While nearly all male (steer) cattle are utilized for eventual consumption, some are held back for breeding purposes as bulls. The steers that are not held back as bulls are castrated and sent along the supply chain, usually to a backgrounding facility or feedlot. A portion of the females (heifers) are maintained and become breeding stock. Breeding stock are then bred on an annual basis with an active breeding life of around nine years. Two indicators are used at the farm-level to indicate the level of inventory rebuilding, which includes the culling and replacement rates. While the culling rate is the percent of herd that is removed and the replacement rate is the percent that is retained for breeding purposes. In North Dakota data have been collected for over 20 years regarding the culling and replacement rates in the state through the CHAPS program. The 20-year average culling and re-
placement rates are 14.1 and 17.8 percent, respectively (Ringwall, 2012). In times of drought, it is typical for the culling rate to increase and replacement rate to decrease.

The decision to expand or reduce a herd relies on the breeding stock. Cattle inventories are often described as a capital good (Jarvis, 1974). This is because the only way to expand the herd size is to forgo current revenue by retaining larger breeding stocks in order to deliver a larger future stock of calves. Once the decision is made to expand the herd, there is a two year lag between birth and slaughter for all animals. It is for this reason that future expectations play an important role in breeding stock and inventory decisions.

Most calves and breeding stock are fed forage on rangeland and crop remnants. In many states, hay production is an important winter supplement used for feed. Hay is also an important indicator of grass availability as it highly correlates with the quality of local forage. Since most ranchers grow feed for their own herds or sell locally, local supplies are an important determinant regarding decisions regarding optimal herd size. For example, cattle prices might be expected to be high in the future, however, a lack of local grass due to drought might cause ranchers to reduce breeding stock. Given a two year lag between birth and when a heifer is prepared to breed, decisions to reduce breeding stock can have long-lasting impacts on herd size.

As in Rucker et al. (1984), we assume that ranch operations determine optimal current and near future herd size based on cattle prices, cost of feed, and the price ratio between cows and calves. Cattle prices provide a somewhat ambiguous signal to ranchers as high prices can provide incentive to expand the herd as expectations for future profits increase, while the opportunity for short-term profits are also present as ranchers can sell off portions of their herd in order to maximize profits. The cost and availability of feed is also an important component of profits. Local hay and grass supplies are the main feed sources for feeder cattle on range operations. For this reason, the optimal herd size is largely dependent on the amount of feed availability. While drought can have an impact on production performance through excessive heat, for most of the cattle growing region, the main impact from drought comes in the form of lack of feed. As Rucker et al. (1984)
explain, feed availability is a more important determinant of herd size than feed price since most feed is grown by the producer. Corn is also an important determinant of rancher profitability and often is reflected in the demand for feeder cattle into feedlot operations. For example, when corn prices are high, feedlot operators find it costly to purchase light weight pens to place on feed and have incentive to leave them on the range for a few extra months. Thus, a low corn price is likely to exert upward pressure on calf prices in order to move cattle to feedlot.

Two additional variables that are importantly related to rancher decisions regarding the optimal cattle inventory and breeding stock include the price ratio between calves and feeder cattle as well as the variance in cattle prices. First, the ratio between calves and feeder cattle prices indicate the relative demand exerted by downstream buyers in the beef industry. This variable is very likely to be related to the price of corn as demand for lighter animals is likely to decrease as the price of corn increases. Second, the variance in the price of cattle is likely to impact rancher decisions, if ranchers are assumed to be risk averse. As said previously, ranchers can respond to market conditions by adjusting breeding stock in order to increase or decrease existing stocks. It is uncertain how ranchers are likely to respond to increased market volatility since volatility impacts the certainty with which prices can be predicted in the near and far term. Thus, a risk-averse producer might prefer to lock-in on a price in times of uncertainty or rebuild their herd in hopes of prices settling in the future.

These factors can be expressed to influence changes in the logarithm of current inventory of beef cows, \( B_t \) in time \( t \). Variables are transformed with logarithms since it provides a more appropriate interpretation in this application. Since drought conditions are likely to impact states with large and small inventories by different magnitudes, a proportional change provides a more appropriate interpretation for our purposes. The same transformation is also used for the second equation which evaluates the logarithm of replacement heifer inventory in time \( t \), denoted as \( R_t \).

Changes in inventory in time \( t \)\(^1\) are hypothesized to be functionally related to the following lagged

\(^1\)Since cattle inventories are intended to represent inventories as of January 1st in year \( t \), lagged variables are the
variables: Lagged dependent variables, Hay is the logarithm of hay production, Corn Price is the logarithm of the real corn price, Calf Price is the logarithm of the real calf price, Cattle Ratio is the cattle price ratio between calves and cows, and Calf COV is the coefficient of variation of nominal monthly calf prices. More specifically, the functional form can be illustrated as shown below:

\[
B_{it} = \alpha_{11} + \alpha_{12}B_{i,t-1} + \alpha_{13}B_{i,t-2} + \alpha_{14}X_{i,t-1} + \epsilon_{1it} \quad (1)
\]

\[
R_{it} = \alpha_{21} + \alpha_{22}R_{i,t-1} + \alpha_{23}R_{i,t-2} + \alpha_{24}X_{i,t-1} + \epsilon_{2it} \quad (2)
\]

where \(X_{t-1} = [\text{Hay}_{t-1}, \text{Hay}_{t-2}, \text{CP}_{t-1}, \text{CAP}_{t-1}, \text{CAP}_{t-2}, \text{CAR}_{t-1}, \text{CACOV}_{t-1}]\) which contains the information a rancher has when determining inventory size for year \(t\). As it typical in panel series, \(\epsilon_{1it}\) and \(\epsilon_{2it}\) contain an individual effect \(c_i\) and a random error component \(v_{it}\), where \(\epsilon_{it} = c_i + v_{it}\). The existence of individual effects, \(c_i\) causes OLS estimates to be inefficient and/or inconsistent when \(c_i \neq c \forall i\). Fixed effects estimators are found to be efficient and consistent estimators when \(c_i\) is uncorrelated with regressors. Fixed estimators essentially adjust equations (1) and (2) to eliminate \(c_i\) to allow for efficient and consistent estimation using OLS. As noted in Greene (2011), first-differenced estimators are preferred over a within fixed effects estimator when \(v_{it}\) follows a random walk.

First-differenced estimators estimate using OLS on the following transformed variables: \(dB_{it} = B_{it} - B_{i,t-1}, dR_{it} = R_{it} - R_{i,t-1}\) and \(dX_{it} = X_{it} - X_{i,t-1}\). Given these transformations, we have the following equations

\[
dB_{it} = \alpha_{31} + \alpha_{32}dB_{i,t-1} + \alpha_{33}dB_{i,t-2} + \alpha_{34}dX_{i,t-1} + v_{1it} \quad (3)
\]

\[
dR_{it} = \alpha_{41} + \alpha_{42}dR_{i,t-1} + \alpha_{43}dR_{i,t-2} + \alpha_{44}dX_{i,t-1} + v_{2it} \quad (4)
\]

Notice that this regression now contains a random error component without \(c_i\) which is eliminated basis for livestock inventory decisions.
with the first differencing process. This allow for simple OLS estimation of the given regressions to obtain unbiased and efficient parameter estimates.

**Empirical Methods**

This study looks to characterize the relationship between beef cattle inventory responses to feed availability, which is largely influenced by weather. To this end, we utilize state-level hay production data in order to capture local feed availability conditions. Rangeland and forage quality scores were also utilized but due to the relatively short data series, were found to be less helpful in characterizing the relationship with beef cattle inventory responses. Hay production highly correlates with the quality of forage and is an indicator of adverse weather that has been used in past studies (Rucker et al., 1984) and provides a measure appropriate for feed availability for winter months. One shortcoming of using a state-level weather variable is that it is not weighted to account for regions where cattle production is more intense. For this reason, hay production provides a better indicator of local weather conditions for cattle production since hay production tends to be positively correlated with cattle production intensity.

Measuring supply responses is utilized with two measures, which includes (1) beef cows and heifers that have calved and (2) replacement heifers over 500 pounds. Both variables provide aggregate measures of beef cattle inventories as of January 1st of the given year and based on surveys from the National Agricultural Statistics Service (NASS). States with less than a 100,000 beef cow inventory were deleted from the sample.\(^2\) Hay production was also collected from NASS and based on the state-level production in millions of tons. Hay production was detrended at the state-level and based on a linear trend and normalized to the fitted 2012 yields. Production variables are shown over time in figure 1. Given the clear trend line differences between pre- and post-1975 dummy variables were also included in regressions but found to be statically insignificant.

\(^2\)This lead to the elimination of 11 states including CT, DE, HI, ME, MD, MA, NH, NJ, RI, VT, AK.
and ultimately left out of the regression. This implies that variables already incorporated into the existing model adequately explain long term inventory movements before and after 1975.

Changes in beef cattle inventory are also partially determined by real cattle prices and real corn prices. Nominal corn and cattle prices were collected from the NASS as the annual average of the prices received by farmers. Corn prices were measured in dollars per bushel, while calf prices were collected as the price received per cwt while the beef cow price was based on the price received per cwt for animals greater than 500 pounds. Cattle and corn prices were normalized by the appropriate Producer Price Index (PPI) code. The Ratio between calf and cow prices were computed to assess the relative value of lighter weight calves to heavier cows. Prices and ratios are shown in figure 2.

Using state-wide panel data series from 1945-2012, we utilize a first-difference fixed effects panel estimator in order to identify short and long run impacts of drought on local cattle inventories with 39 states included in the cross section. Observations were weighted by cattle inventory in order to accurately estimate while accounting for differences in the size of cattle industries within each state. Therefore, the results are more consistent with national-level movements while utilizing state-level units. The results are shown below in table 1.

Prices appear to have significant impacts on beef cow inventory and replacement inventories. For example, a 1% increase in the price of calves in year $t$ is correlated with a 0.09% and 0.08% increase in beef cow inventory in years $t + 1$ and $t + 2$, respectively. However, this increase in the price of calves would also lead to a 1% reduction in the cattle price ratio, leading to a 0.17% increase in inventory. This implies that an increase in the price of calves has a net positive impact on inventories if cow prices are held constant. The reverse is true if the cow price moves along with the price of calves, which is more likely to be the case given that the price for cows and calves tend to be highly correlated. For replacement inventories only the second lag is statistically significant.

---

3 Corn production factors utilized “WPU01220205” while cattle prices were indexed by Slaughter steers and heifers “WPU013101” and normalized to 1982 prices.
4 Given prices received from 1945-2012, the correlation between these two series was 0.94 indicating a high degree
Table 1: Weighted First Differenced Fixed Effects Parameter Estimates, 1947 - 2012 (n=39)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Beef Cow Inventory ($B_t$)</th>
<th>Parameter Estimate</th>
<th>Std. Error</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td></td>
<td>0.0062</td>
<td>0.0014</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>$B_{t-1}$</td>
<td></td>
<td>0.3128</td>
<td>0.0204</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>$B_{t-2}$</td>
<td></td>
<td>0.1423</td>
<td>0.0203</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>Hay$_t$-1</td>
<td></td>
<td>0.0683</td>
<td>0.0106</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>Hay$_t$-2</td>
<td></td>
<td>0.0662</td>
<td>0.0109</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>Corn Price$_t$-1</td>
<td></td>
<td>0.0092</td>
<td>0.0083</td>
<td>0.2698</td>
</tr>
<tr>
<td>Calf Price$_t$-1</td>
<td></td>
<td>0.0943</td>
<td>0.0560</td>
<td>0.0922</td>
</tr>
<tr>
<td>Calf Price$_t$-2</td>
<td></td>
<td>0.0751</td>
<td>0.0115</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>Cattle Ratio$_t$-1</td>
<td></td>
<td>0.1707</td>
<td>0.0827</td>
<td>0.0391</td>
</tr>
<tr>
<td>Calf COV$_t$-1</td>
<td></td>
<td>0.0014</td>
<td>0.0003</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td></td>
<td>0.1814</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F-stat</td>
<td></td>
<td>60.5582 (p-value &lt; 0.0001)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables</th>
<th>Replacement Heifer Inventory ($R_t$)</th>
<th>Parameter Estimate</th>
<th>Std. Error</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td></td>
<td>0.0021</td>
<td>0.0026</td>
<td>0.4168</td>
</tr>
<tr>
<td>$R_{t-1}$</td>
<td></td>
<td>-0.0043</td>
<td>0.0209</td>
<td>0.8359</td>
</tr>
<tr>
<td>$R_{t-2}$</td>
<td></td>
<td>0.0540</td>
<td>0.0209</td>
<td>0.0097</td>
</tr>
<tr>
<td>Hay$_t$-1</td>
<td></td>
<td>0.0821</td>
<td>0.0209</td>
<td>0.0001</td>
</tr>
<tr>
<td>Hay$_t$-2</td>
<td></td>
<td>0.1420</td>
<td>0.0213</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>Corn Price$_t$-1</td>
<td></td>
<td>-0.0362</td>
<td>0.0164</td>
<td>0.0274</td>
</tr>
<tr>
<td>Calf Price$_t$-1</td>
<td></td>
<td>0.0611</td>
<td>0.1081</td>
<td>0.5722</td>
</tr>
<tr>
<td>Calf Price$_t$-2</td>
<td></td>
<td>0.1295</td>
<td>0.0224</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>Cattle Ratio$_t$-1</td>
<td></td>
<td>0.0802</td>
<td>0.1603</td>
<td>0.6167</td>
</tr>
<tr>
<td>Calf COV$_t$-1</td>
<td></td>
<td>0.0020</td>
<td>0.0005</td>
<td>0.0001</td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td></td>
<td>0.0419</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F-stat</td>
<td></td>
<td>11.8971 (p-value &lt; 0.0001)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

indicating that an increase in the price of calves by 1% in year $t$ is correlated with an increase in inventories by 0.13%. For replacement heifer inventories, the price ratio is large in magnitude but not statistically significant. Corn prices are also found to have a negative and statistically significant relationship with replacement inventories. Rising corn prices are likely to indicate lower demand for feeder calves due to the high cost of feed.

Hay production in both equations has a positive impact on inventories. For example, a 10% reduction in hay production would be expected to lead a reduction in beef cow inventories by 0.68% and replacement heifers by 0.82% in the next year. This impact is strong in the second lagged year where a reduction in beef cow inventories is expected to be 0.66% and a reduction in replacement heifer inventory by 1.42%. This result provides some insight into why herds are slow to recover as a distribution of detrended hay production tends to be left skewed where large negative deviations are more likely than large positive deviations. While prices are typically thought to provide the economic incentive needed to expand herds, results in this study show that those incentives are of positive correlation.
relatively small when considering the incentive to reduce herds in times of limited feed availability. These results provide insights into the recovery time associated with and degree of rebuilding cattle herds following a drought. Initial results show that regional cattle inventories decrease for three years before some rebuilding occurs. While these findings conform to theoretical production behavior, identifying the magnitude of this change can be very informative in understanding long-run cattle movements.

Variance in calf prices lead to inventory increases in both regressions. For heifer replacement inventories, a one-percent increase in the coefficient of variation in calf prices is correlated with an increase of inventories by 0.20%. This is a similar increase for beef cattle inventories. This would indicate that ranchers respond to additional risk by increasing inventories in order to sell herds at a later time period.

One example of a large reduction in cattle herd resulting from loss of grass is the central plains drought of 2002. Colorado and Wyoming both had more than 50% of the rangeland and pasture rated as 'very poor' based on the NASS rating system. Detrended hay production in both states fell by more than 20% over the average production in the previous 5 years. In 2003 and 2004, the beef cattle inventory in Colorado fell by 12.0% and 17.1%, respectively. The model performed relatively well as it predicted decreases in Colorado beef cattle inventories of 13.1% and 19.5% in 2003 and 2004. In Wyoming, beef cattle inventories fell by 12.1% in 2003 and 1.3% in 2004 which is relatively close to the predicted values of 13.6% and 1.4%, respectively. While both Colorado and Wyoming steadied their losses in cattle inventories, their inventories have not yet recovered to their pre-2002 levels.

**Conclusions**

Over the coming century, natural weather cycles and emissions of greenhouse gases and other radiatively-active species from human activities are suspected by many to drive significant changes
in global climate. Determining the potential impacts of climate change, and deciding on the adaptation and mitigation strategies required to, in the words of the United Nations Framework Convention on Climate Change (UNFCCC), "prevent dangerous anthropogenic interference with the climate system," has become one of the main priorities of national, state, and city governments around the world. Large amounts of resources are currently devoted to evaluating the impact of predicted global climate changes on agriculture.

Results in this research demonstrates that modest changes in drought conditions have significant impacts on cattle inventories for multiple years. Further, multi-year droughts are found to be particularly damaging to local declines in herd size. While one might think that strong cattle prices are likely to provide incentive to rebuild herds quicker, the impact is dampened which may be due to the added volatility in cattle markets. While a long term trend is accounted for, herds are found to be reduced due to drought and longer than a few years to recover.

While agricultural prices are more volatile, risk management strategies are also more utilized by farmers in the form of crop insurance, futures and options markets, as well as forward contracts. While price risk and crop yield insurance are commonly used in many crop operations, livestock producers still producers amidst the weather-driven risks. Profit-maximizing producers are shown to respond to economic incentives which include reducing breeding herds in times of drought and rebuilding in times of high prices. However, the incentives to continue cow-calf production in times of reduced exposure in other areas of agriculture remains an area open to speculation.
References


Billings Gazette (2011) ‘Montana hay heads to drought-stricken texas market.’ August 22


period analysis of two common livestock management strategies given fluctuating precipitation and variable prices.’ *Journal of Agricultural and Applied Economics* 42(2), 177–191


Schlenker, W., and M.J. Roberts (2009) ‘Nonlinear temperature effects indicate severe damages to u.s. crop yields under climate change.’ *Proceedings of the National Academy of Sciences* 106(37), 15594–15598


Figure 1: Plots of Inventory and Production Variables, 1947-2012
Figure 2: Plots of Prices and Price Ratios, 1947-2012