Experiments in Ranching: Rain-Index Insurance and Investment in Production and Drought Risk Management

Trisha Shrum

March 13, 2018

Abstract

Rainfall is one of the biggest predictors of profit in the ranching industry. Yet, rainfall varies widely from year to year. A major drought can put ranchers out of business and even a minor drought can significantly reduce their profit. In response to this risk, the USDA Risk Management Agency has developed a new policy called the Pasture, Rangeland and Forage (PRF) Insurance. This insurance is unique in the United States because it pays out based on rainfall, not measured losses. Rain-index policies such as the PRF program can reduce problems of moral hazard because insured ranchers cannot affect their own payout once they have purchased the policy.

However, the rain-index insurance may still affect rancher behavior. First, with the current levels of subsidies, the rain-index policy has a positive expected value: on average, it pays out more in indemnities than ranchers pay in premiums. Increasing the profitability of ranching is likely to increase the intensity of ranching, both by inducing market entry and by increasing the number of cattle in an optimally profitable herd for a given rancher. When cattle production is more profitable, the marginal product of the base herd and other production inputs increase leading to higher levels of investment in those inputs. Second, the rain-index policy transfers drought risk from the rancher to the insurance system. Transferring drought risk may lead ranchers to

reduce investments in other types of drought risk management strategies. Conversely, the rain-index insurance could increase investmentsin drought risk management if the ranchers were previously cash constrained.

In this paper, I introduce the Drought Ranching Insurance Response R Model (DRIR-R) and use a ranching simulation driven by the model to test these questions experimentally with decision-makers. The DRIR-R model simulates a cow-calf ranching operation in periodic drought, with participants choosing their level of investment in supplemental feed to offset low forage growth in drought years. They also determine the number of cows and calves they sell each year which affects their current revenues and future herd size. Among the study population, I find that the rain-index insurance does not affect average herd size but does reduce the likelihood of herd liquidation associated with a market exit. I also find that the rain-index insurance increases the investment in supplemental feed, especially for those who are risk averse. These experimental findings are a first step in using the DRIR-R model simulation to better understand the impact of the rain-index insurance on two important aspects of the cattle ranching industry that have long-term natural resource impacts: grazing intensity and drought adaptation.

Acknowledgements

Funding for this work was provided by the University of Colorado-Boulder Grand Challenge for Space and Earth Sciences, with additional funding from the Western Water Assessment under National Oceanic and Atmospheric Administration Climate Program Office grant #NA10OAR4310214. I would also like to acknowledge the work of Adam McCurdy, Joe Tuccillo and Max Roland in assisting in the development of the user interface application, Evan Lih and Travis Williams for their research assistance, and William Travis for the research program, support, and guidance.

1 Introduction

As the climate warms and precipitation patterns change, adaptation to new climate regimes and resilience to climate variability will be paramount to moderating the impacts of climate change. Across the world, agriculture is the most vulnerable economic sector to climate change impacts (Antle, 2008). Globally, agriculture only generates 3% of total GDP; however, in developing countries, much of the population is still dependent on these volatile industries, as more than 25% of their respective GDP comes from crop production and ranching (World Bank, 2012). Even in the United States, around one million individuals are employed in ranching and agriculture (US. Department of Labor, 2017). The cattle industry alone produces $61.2 billion in commodities annually (USDA Economic Research Service, 2017). From a land use perspective, the importance of ranching is even more pronounced: 40% of land use in the United States is shared between ranching and farming, with a majority of farms supporting or participating in the ranching industry (USDA, 2014; Farmland Information Center, 2014).

Climate change is already affecting agricultural production in many regions around the world with more negative than positive impacts, especially in the response of agricultural systems to climate extremes (Porter et al., 2014). As the climate continues to warm, the impacts on agriculture will become even more serious. Beginning in 2050, agricultural yields decrease in 70% of projected model scenarios (Porter et al., 2014). However, adaptation can improve agricultural yields by 15-18% (Porter et al., 2014). For livestock production, adaptation strategies to deal with current climate risks, such as inter-annual volatility in precipitation, provide a good template for adaptation to future climate change (Thornton et al., 2009; Derner et al., 2017; Shrum et al., 2018).

Drought is already the most serious risk to ranching productivity. For example, the

2012-2013 North American drought caused massive sell-offs, leading to the smallest total US cattle herd size in 60 years (Waters, 2013). Even five years later, the market still has not recovered. With climate change, drought risk will loom larger as higher temperatures lead to higher water demand for forage growth. Ranching is vulnerable to climate change due to the major impacts from volatility in rainfall and extreme heat (Reeves and Bagne, 2016). The extent of the vulnerability depends on the frequency and severity of drought and extreme heat, the sensitivity of the ranching system to those hazards, and the adaptive capacity of the ranching system (Adger, 2006; Derner et al., 2017). Rainfall is one of the key inputs to cattle ranching in the western United States and around the world (Conley et al., 1999). Most of the ranching in the United States relies on rainfall, not irrigation (McNew et al., 1991; Conley et al., 1999; Frisvold et al., 2013; Gillam, 2012). Temperature also has an important role: extreme heat stresses cattle which can reduce growth rates and increase mortality (Hahn, 1999).

The impacts of climate change on rangeland forage productivity are complex: there are both direct and indirect drivers to consider, and some effects are positive while others are negative (Porter et al., 2014). The main direct drivers are temperature, carbon dioxide concentrations, and precipitation. Higher temperatures are expected to increase the length of the growing season in the United States, but, depending on precipitation levels, may decrease the quality of forage (Izaurralde et al., 2011). Increases in CO_2 concentrations tend to have a positive impact on the growth of forage species, although due to the differential impact on C3 and C4 plant species, changes in CO_2 concentrations may change the plant community dynamics in rangelands (Izaurralde et al., 2011). The biggest source of uncertainty is precipitation. Precipitation is likely to become more variable, which can significantly reduce the net primary productivity of rangelands, holding other variables, like total rainfall, constant (Knapp et al., 2002; Fay et al., 2003). In general, in areas where soil moisture is a limiting factor in growth, if rainfall increases, then forage productivity will also increase (Izaurralde et al., 2011). Likewise, if rainfall declines, then forage productivity will also drop.

The impacts of climate change on cattle reproduction and growth are more straightforward. The IPCC has high confidence that higher temperatures will reduce cattle growth rates (Porter et al., 2014). The relationship between heat stress and decreased cattle productivity is well-established (St-Pierre et al., 2003; Brown-Brandl et al., 2006). While even moderate heat stress can slow down cattle's growth, extreme heat can be deadly. For example, the prolonged heat waves in France in 2003 and 2006 caused cattle mortality rates of 24% and 12% respectively (Morignat et al., 2014). Additionally, the IPCC has high confidence that pathogens that affect livestock will increase their geographical range (Porter et al., 2014). Tropical pathogens may even extend into North America and impact U.S. ranching operations.

Climate change is expected to increase temperatures across the Western United States (Polley et al., 2013). Predictions for changes in average precipitation are mixed (Polley et al., 2013), but precipitation is likely to have higher volatility leading to more frequent and more severe droughts (Ault et al., 2014). Since 1950, much of the Western United States has actually gotten wetter. The first half of this period was much drier and punctuated with extreme droughts while the second half of this period had considerably more precipitation Melillo et al. (2014); Scasta et al. (2015). However, for the latter half of the twenty-first century, this trend is expected to reverse, at least in the Southern Great Plains and the Southwest (Polley et al., 2013). Soil moisture levels are expected to drop 2-10% in most of the contiguous United States (Dai, 2013), with more severe drops corresponding to areas with higher concentrations of ranching operations. In the Southwest and Central Plains, model results show that with moderate to high future emissions scenarios, drought towards the end of the twenty-first century may reach extremes that are unprecedented, surpassing even the extreme droughts of the Medieval Climate Anomaly (1100-1300 CE) (Cook et al., 2015).

The USDA Risk Management Agency offers rainfall-index insurance to help ranchers through periods of low rainfall that tend to reduce their income. The Pasture Rangeland and Forage (PRF) rainfall-index insurance policy was rolled out starting with a few states in 2007 and was made available to the contiguous forty-eight states in 2016. The PRF policy pays an indemnity on insured acreage when precipitation falls significantly below the historical average for the area. Because the payouts do not depend on actual losses, this type of insurance is meant to minimize the moral hazard associated with the policy. While this policy is intended to help ranchers deal with drought risk, it could incentivize maladaptive behaviors. Because the policy reduces the income risk of drought, it may increase the returns to investment in production inputs, such as herd size, and reduce the return on investment in risk reducing inputs, such as drought adaptation investments. As a result, the policy may affect the optimal size of the ranchers' herd and the optimal investment in drought adaptation in ways that have longer term consequences for the vulnerability of ranching to climate change impacts.

The goal of this study is to test whether the rain-index insurance affects ranch management in ways that will increase or decrease vulnerability to more intense drought and heat. Specifically, I test the following two hypotheses with an experimental simulation:

H1: The availability of rain-index insurance leads to an increase in the average size of cattle herds because the expected return on investment in cattle production will increase when drought risk is mitigated.

H2: The availability of rain-index insurance will decrease investment in (i.e., crowd-out) other drought adaptation strategies because insurance serves as a substitute.

The major contributions of this paper are two-fold. First, I introduce the Drought Ranching Insurance Response R Model (DRIR-R), which to my knowledge, is the first decision model to incorporate the USDA's rainfall-index insurance. Second, I test the model in a randomized control experiment. This experiment is a preliminary test of the experimental simulation and of the hypotheses described above. Additional experiments with this model will be carried out with ranchers currently operating in the Great Plains region. Because cattle ranchers are a relatively small population, it is important to thoroughly vet the model and experimental paradigm with a test population before deploying it with a large sample of ranchers.

The rest of the paper is organized as follows. Section 2 reviews the economic and policy background on agricultural insurance as well as the links between climate and cattle production. Then, Section 3 lays out the coupled natural-human system model that drives the experimental simulations. Section 4 reviews the experimental methods used in the simulations and section 5 goes through the analysis of the experimental results. Finally, Section 6 offers conclusions from our experiments and a roadmap for future research with this experimental model.

2 Agricultural Insurance: Policy and Economic Theory

The United States has a long history of providing assistance to the high-risk business of agriculture. With the Federal Crop Insurance Act of 1980 and the Agriculture and Food Act of 1981, policymakers shifted the policy trajectory towards heavier reliance on crop insurance to reduce the need for *ex post* weather and natural disaster assistance (Barnett, 2000; Coble and Barnett, 2012). Yet, even after subsidizing the program, disaster assistance was still very common: sixty percent of farms received it between 1987 and 1994 (Barnett, 1999). Additional policies passed in 1994 and 2000 provided free catastrophic coverage and increased crop insurance subsidies (Coble and Barnett, 2012). Premium subsidies grew from 20 percent in 1980s to the current levels of 60 percent for corn and soybeans (Annan and Schlenker, 2015). In addition to the subsidy, premiums are required to be set at the actuarially fair price, and the private insurance agents' administrative costs of selling and maintaining policies are reimbursed by the federal government.

As of 2016, U.S. ranchers have two main choices for federal insurance for their ranching operations: the Noninsured Crop Disaster Assistance Program (NAP) and the Pasture, Rangeland and Forage (PRF) rain-index insurance. NAP supplies aid to producers of non-insurable crops (e.g., crops planted and grown for livestock consumption) in the event of a natural disaster that results in crop losses or lower crop yields. The PRF rain-index insurance program is designed to provide area-based insurance coverage to rangeland, perennial pasture, or forage used to feed livestock against low precipitation (USDA Risk Management Agency, 2015). The area-based characteristic of the PRF program indicates that insurance payouts are based on gridded precipitation data from the National Oceanic and Atmospheric Administration Climate Prediction Center (NOAA CPC), rather than an individual producer's loss experience. The PRF rain-index insurance program is the third largest crop insurance program in the United States. In 2016, 43 million acres were insured with \$127.8 million in subsidies and \$70.8 million paid out to rancher in indemnities (USDA, 2016).

Insurance allows agricultural producers to reduce their exposure to risk and smooth their income. In theory, a risk-averse producer would have positive demand for crop insurance at actuarially fair prices (Ahsan et al., 1982). Yet we observe under-insurance even at subsidized premiums, which leads us ask what other factors of decision-making might be at play. Incentives to purchase insurance can be broken up into four major components: 1) risk aversion of the producer, 2) income transfers from the subsidy, 3) adverse selection, and 4) moral hazard (Just et al., 1999; Coble and Knight, 2002).

Risk aversion is likely to increase demand for the rain-index insurance while dampening the impact of the insurance on risk-taking behavior. We expect ranchers who are more risk averse to have a higher willingness to pay to avoid or reduce their risk. We would also expect that for a given level of insurance, those who are more risk averse are more likely to still hedge against risk that remains once again because they have higher demand for risk reduction.

Adverse selection in agriculture is not a straightforward story of agricultural producers knowing their own risks better than the insurers. Demand for insurance to insure weather related risks may be hampered by decision-makers tendency towards certain cognitive errors when dealing with low probability events (Kunreuther, 1996). Evidence suggests that decision-makers have a difficult time estimating their true risk of low probability events, like severe drought (Kunreuther, 1996; Burby, 2001). These cognitive errors may lead them to under-insure. This issue is well established for non-agricultural disasters, but more research is needed to better understand the role that cognitive errors about risk may play in agricultural insurance (Coble and Barnett, 2012; Du et al., 2016).

Moral hazard is a major problem for crop insurance, particularly programs that are based on actual production or revenues. There is evidence, for example, that agricultural producers have responded to crop insurance for corn and soybeans by reducing adaptive behaviors that minimize the impact of extreme heat (Annan and Schlenker, 2015). Annan and Schlenker find that insured crop yields are 43% to 67% more sensitive to extreme heat than uninsured crops, implying that farmers investing less in adaptive behaviors when the losses are covered. They also find that insured crops are less sensitive to sub- or supra-optimal precipitation levels. However, the crop insurance in their study pays out indemnities based on actual losses which leaves the policy highly vulnerable to moral hazard. Because the losses are insured, there is less incentive to invest in other measures that reduce losses. Hence, one of the major appeals of rain-index insurance is that it reduces moral hazard (Carter et al., 2016). Insurance indemnities depend on rain alone; no matter how producers respond to drought, they still receive the same payouts. Yet, because rain-index insurance reduces the financial consequences of drought, it changes the payoffs to investments in drought risk reduction (Fuchs et al., 2011). As such, we would expect to see cattle ranchers substitute away from investments in drought adaptation. This substitution in investment, paired with the increased profitability of ranching due to the income transfer of the subsidy, leads us to hypothesize that ranching will become more profitable, which will lead to an intensification of cow-calf production, both for individual ranchers and for the industry as a whole.

There has been limited research on the impacts of rain-index insurance on risk-management, especially in the U.S. where such policies are relatively new. In a recent randomized control field study, Karlan et al. (2014) found that providing rain-index insurance to farmers in Ghana increases risk-taking behavior and increases investment in cultivation. For example, farmers increase the number of acres cultivated by 12.5% when they have rain-index insurance compared to a control group without insurance. They also increase the production of rainfall-sensitive corn by 9% and decrease other income generating activities. Other studies that explore the impacts of weather-based insurance on agricultural investment and risk management reinforce these findings (Cole et al., 2013; Cai, 2013; Cai et al., 2015). However, there is a key distinction between the investment in inputs to increasing production regardless of drought risk (e.g., increasing the size of the herd) and the investment in drought risk reduction (e.g., feed supplements, trucking herds to rented pasture, or early sales).

Karlan et al. (2014) developed a basic model of the impact of rain-index insurance on farmers who lack complete risk pooling for losses in revenue due to low levels of rainfall (referred to in this paper as "the Karlan model"). Here, I briefly review the model, then I tailor it to represent the RMA rain-index insurance market in the United States.

The Karlan model includes two periods ($t = 0, 1$) with two states of the world ($s \in G, B$). Preferences over consumption in the two periods are:

$$u(c^0) + \beta \sum_{s \in S} \pi_s u(c_s^1) \tag{1}$$

where π_s is the probability of state s and β is a discount factor.

With perfect credit markets, assets can be borrowed or lent at a risk-free interest rate of $R = 1/\beta$. With complete risk pooling, the authors assume access to an informal ex-post risk pooling group that, regardless of whether a good or bad state occurs in the second period, each household consumes the expected value of its second period consumption. In other words, $c_G^1 = c_B^1 = \sum_{s \in S} \pi_s u(c_s^1)$.

The rancher, or, in Karlan et al's model, the farmer, has a concave production function, $f_s(x)$, that takes a vector of inputs, x, committed in the first period to produce output in the second period. They assume two inputs: a risky input, x_r, and a hedging input, x_h. The risky input outperforms the hedging input in a high rainfall state ($s = G$). Likewise, the hedging input outperforms the risky input in a low rainfall state ($s = B$). In other words, the marginal product of x_r is lower in state B than in G and the marginal product of x_h is higher in state B than in G.

The risky inputs in the Karlan model are production inputs like "field preparation, fertilizer and pesticide use, weeding and cultivation activities" (Appendix 1, pg 1). In this study, the risky input is simply herd size. The cost of the herd consists of both the opportunity cost of not selling the cow and the marginal operating costs of keeping them in the herd. The marginal product of the herd size depends on rainfall with a higher marginal product in a high rainfall state than in a low rainfall state.

The hedging inputs in the Karlan model is the production input of irrigation, which is not available in the Karlan et al. (2014) experimental study. In this study, the hedging input is supplemental feed. (We assume no irrigation is available.) The marginal product of supplemental feed is higher in the low rainfall state than in the high rainfall state. We assume that supplemental feed cannot be stored or resold, so excess supplemental feed has a marginal product of zero.

Karlan et al. (2014) predict that while index insurance increases investment in production overall, it may decrease investment in risk reduction. Insurance reduces the financial risks of drought and thus reduces the incentive to mitigate those risks with other methods. If the model and the assumptions for its translation from crop production to ranching hold, then rain-index insurance should increase herd size and decrease investment in supplemental feed. We will test these key predictions in this experiment.

3 Dynamic Optimization Model

In this section, I lay out the dynamic optimization model that is used in the experimental simulation. Where a traditional dynamic optimization model would use a numerical simulation, such as a Monte Carlo analysis, to find the optimal choice variables, I use human subjects to interact dynamically with the model through a user interface. After I describe the model in this section, I will detail the methods and results from the first randomized control experiment that tests the impact of rain-index insurance on investment in risky and hedging inputs (herd size and supplemental feed, respectively).

In this coupled-natural-human-systems dynamic optimization production model, ranchers maintain a herd of cows to produce calves for sale at market. The variable inputs to the production of calves are cows and forage (Comerford, 2018). Forage availability is determined by rainfall (Cable, 1975; Houerou and Hoste, 1977; Yang et al., 2008), which is determined exogenously by drawing from historical rain gauge records, a forage production function, and hay, which may be purchased on an annual basis. The stock of cows in a herd can be increased or decreased over time by selling cows and calves and maintaining forage that sustains calf reproduction.

Year is indexed with t and month is indexed with i. The goal of the player is to maximize the following objective function:

$$\max_{C(a_t),x_t,y_t} \sum_{t=1}^{T} \pi_t(1+r)^{-t} \tag{2}$$

subject to constraints on herd growth and forage potential as well as constraints on a number of key variables described in the sections that follow.

3.1 Choice Variables

This model includes three choice variables: $C(a_t)$, the investment in drought adaptation in year t, x_t, the percentage of calves sold in year t, and y_t, the percentage of cows sold in year t.

In this model, drought adaptation is assumed to be an irreversible investment under uncertainty (Dixit and Pindyck, 1994; Fankhauser et al., 1999); the investment must be made halfway through the growing season when only the first half of the growing season's rainfall is known and overinvestment (i.e. extra hay) does not carry over from year to year. In the simulation, we simplify mid-year drought adaptation by allowing one option: the purchase of hay. In contrast to the set-up of our model, hay can actually be stored from year to year. However, other drought adaptations, such as the renting of additional pasture, early weaning of calves, and culling of the herd are irreversible (Shrum et al., 2018). Buying of hay is, therefore, a proxy for a number of different drought adaptation investments. It is an irreversible annual investment for simplification.

In the simulation, the player is given information about rainfall from the previous November to June. Then, they are given advice about how much hay they should purchase if they expect rainfall for the rest of the season to be normal, above normal, or below normal (defined as one standard deviation above or below the average). They choose the dollar amount of hay they would like to purchase given their expectations and risk preferences. When they learn the actual rainfall for the rest of the year, then they realize the costs of perfect adaptation. However, the perfect adaptation cost is not stated explicitly in the simulation. The lower bound on drought adaptation is 0%. There is no upper bound on drought adaptation, but there are strong financial incentives to not over-invest. Drought adaptation, a_t, is further defined in Section 3.3.1.

In the simulation, the player chooses how many cows and calves to sell at the end of each growing season. The lower bound on calf sales, x_t, is 50% due to the fact that male calves are assumed to have no economic value if retained in a cow-calf operation beyond the yearling stage (Schroeder and Featherstone, 1990; Fausti et al., 2003; Frasier Pope et al., 2011). The lower bound on cow sales is 0%. The upper bound on both variables is 100%. We make the simplifying assumption of no relationship between culling cows and average weaning percentage. In reality, a cow-calf operation sells cows that do not produce calves in order to keep the herd at optimal calf production. If they do not sell cows, the weaning percentage would begin to fall. We justify this simplification by assuming a young herd that is not yet experiencing declining fertility due to age and by assuming that all cows have an equal likelihood of producing a calf in a given year.

3.2 Stock Variables

Two variables, herd size and forage potential are stock variables that depend on their values in previous years and other choice and exogenous variables.

3.2.1 Herd Size

Herd size, θ_t, is a stock variable that grows or shrinks according to the following equation:

$$\theta_t = \theta_{t-1}(1 - d_{t-1})(1 - y_{t-1}) + \theta_{t-2}\omega_{t-2}(1 - x_{t-2}) \tag{3}$$

where d_t is the death rate of cows, y_t is the percentage of cows sold in year t, ω_t is the percentage of cows who successfully birth and wean a calf in year t (referred to as weaning percentage), and x_t is the percentage of calves sold in year t.

In the simulation, we set the death rate of cows, d_t, to a constant value of 4% per year (Fall et al., 1982; United States Department of Agriculture, 2011). In future work, the death rate could more realistically depend on variables such as forage availability, extreme heat exposure, and age.

The weaning percentage, ω_t, depends on the health of the herd in year t and year $t-1$, which is assumed to be fully based on total available forage per cow, λ_t and λ_{t-1} (Figure 1). In the simulation, the weaning percentage maximum is 88%, represented by $\tilde{\omega}$ (Longworth and McLeland, 1972; Nob, 2002; Godfrey et al., 2009; Comerford, 2017).[1] Weaning percentage in year t is given by:

[1] Our chosen value of 88% weaning percentage maximum is the average of multiple sources. Weaning percentages in these sources range from 81% to 93%, with an average at 88%.

$$\omega_t = \begin{cases} \tilde{\omega} & \text{if } \lambda_t, \lambda_{t-1} \geq 1 \\ \tilde{\omega} * \lambda_t^{(1/4)} & \text{if } \lambda_t < 1 \wedge \lambda_{t-1} \geq 1 \\ \tilde{\omega} * \lambda_{t-1} & \text{if } \lambda_t \geq 1 \wedge \lambda_{t-1} < 1 \\ \tilde{\omega} * \lambda_t^{(1/4)} * \lambda_{t-1} & \text{if } \lambda_t, \lambda_{t-1} < 1 \end{cases} \tag{4}$$

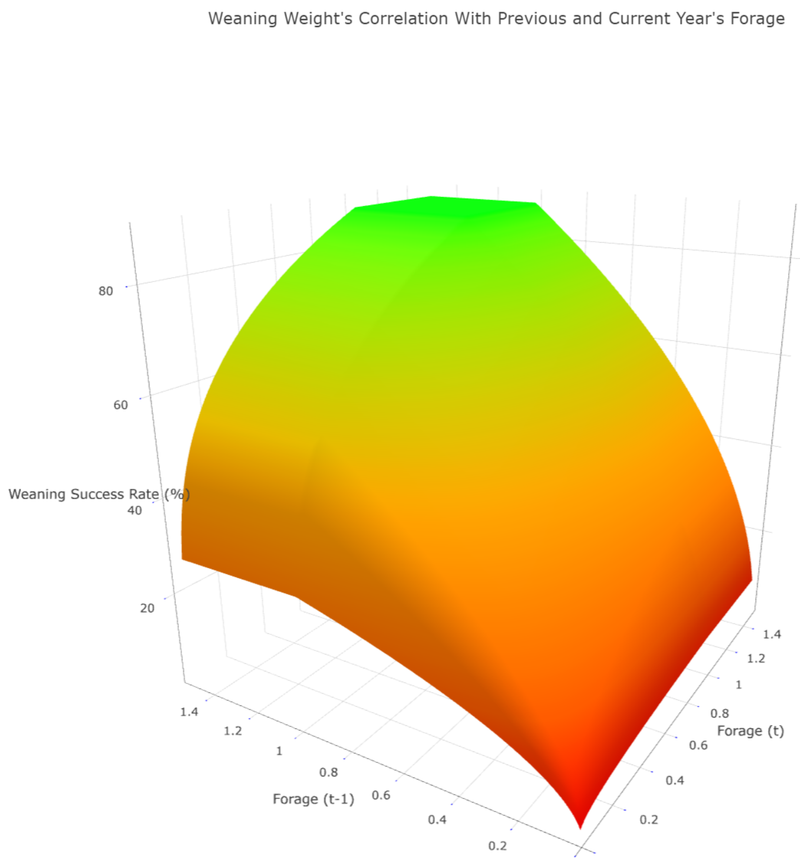

Figure 1: Weaning percentage as a function of forage availability in year t and year t-1.

Low forage availability in a given year affects the survival rate of calves that have already been born, but the effect is quite small.[2] Cows and calves stressed by underfeeding may be more likely to fall ill, but only under extreme circumstances would you see major mortality impacts. However, the forage availability in the year prior has a major impact on the fecundity of cows for the next year (Rankin, 2017). If cows have low body condition (i.e. are underweight) due to underfeeding, their birth rates will drop significantly (Eversole et al., 2009; Moriel, 2016). Forage availability, λ_t, is further described in Section 3.3.1.

3.2.2 Forage Potential

Forage potential is a vector that translates monthly rainfall into annual forage production. It is a stock variable that changes according to the following equation:

$$\vec{\alpha}_t = \vec{\alpha}_{t-1}\left(1 - \frac{G_{t-1}}{\gamma}\right), \tag{5}$$

$$\text{where } \tilde{\alpha} \equiv \sum_{i=1}^{12} \alpha_i \leq 1 \tag{6}$$

Forage potential increases or decreases based on the grazing pressure, G_t, on the land (Smart et al., 2010; George and Lile, 2009)[3]. If $G_t > 0$, then forage potential decreases (subject to a minimum of 0). If $G_t < 0$, then forage potential increases (subject to a maximum, $\tilde{\alpha}$, defined in eq. 6). This maximum is the starting point of the model and is determined by the Major Land Resource Area (MLRA) plant growth curves (Figure 2). MLRAs are designated by the USDA Natural Resource Conservation Service based on similar physiography, geology, climate, water, soils, biological resources, and land use

[2]The survival rate of newborn calves is affected by colostrum-the milk that is produced by cows right after birth. In order to produce high-quality colostrum, cows need adequate amounts of forage just before calving. (Kniffen; Neel, 2011; Rutter et al., 2000b). However, there are supplements that ranchers can choose from to alleviate the possibility of low-quality or lack of colostrum (Randle, 2015; Rutter et al., 2000b; Daly, 2012).

[3]Smart 2010 shows that stocking rate (SR) has a negative correlation with peak standing crop (PCS), which is correlated to forage potential.

(USDA, 2005). The MLRAs for the state of Colorado are shown in Figure 3.2.2. The model uses a plant growth curve for MLRA 67B, an area in Eastern Colorado that includes the Central Plains Experimental Range (CPER) where we situate our model simulation. The specific growth curve used is for a Western Wheatgrass, Blue Grama, Green Needlegrass, Fourwing Saltbush Plant Community with upland, fine textured, loamy soils (Sprock et al., 2004).

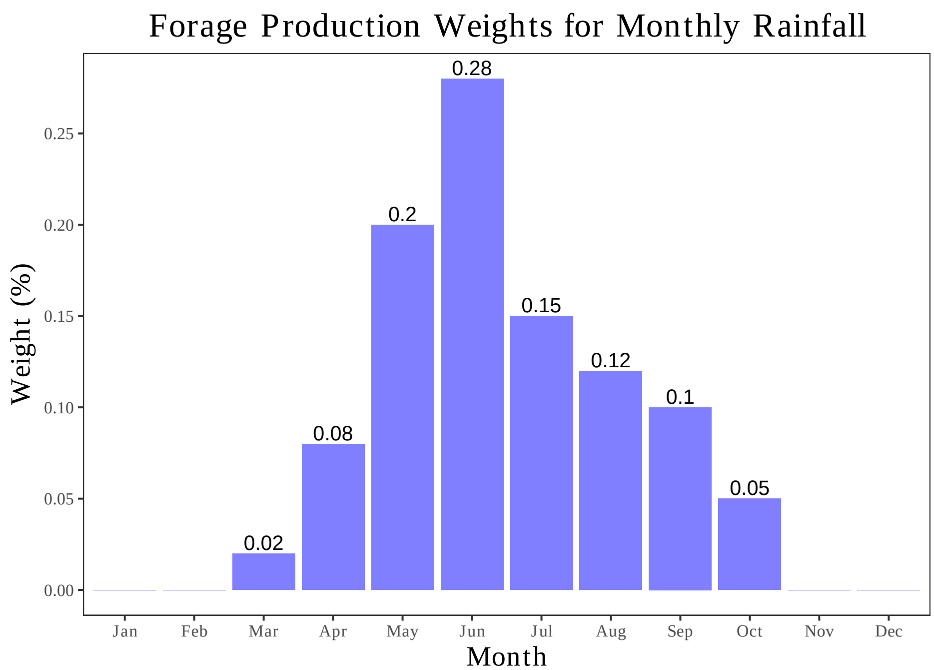

Figure 2: Forage potential, α_0, based on the MLRA growth curve number CO6701: Cool season/warm season co-dominant; MLRA-67B; upland fine textured soils.

For each monthly value in the vector α_t, the previous years' forage value is multiplied by a percentage that is determined by the grazing pressure and a scaling factor, γ. The

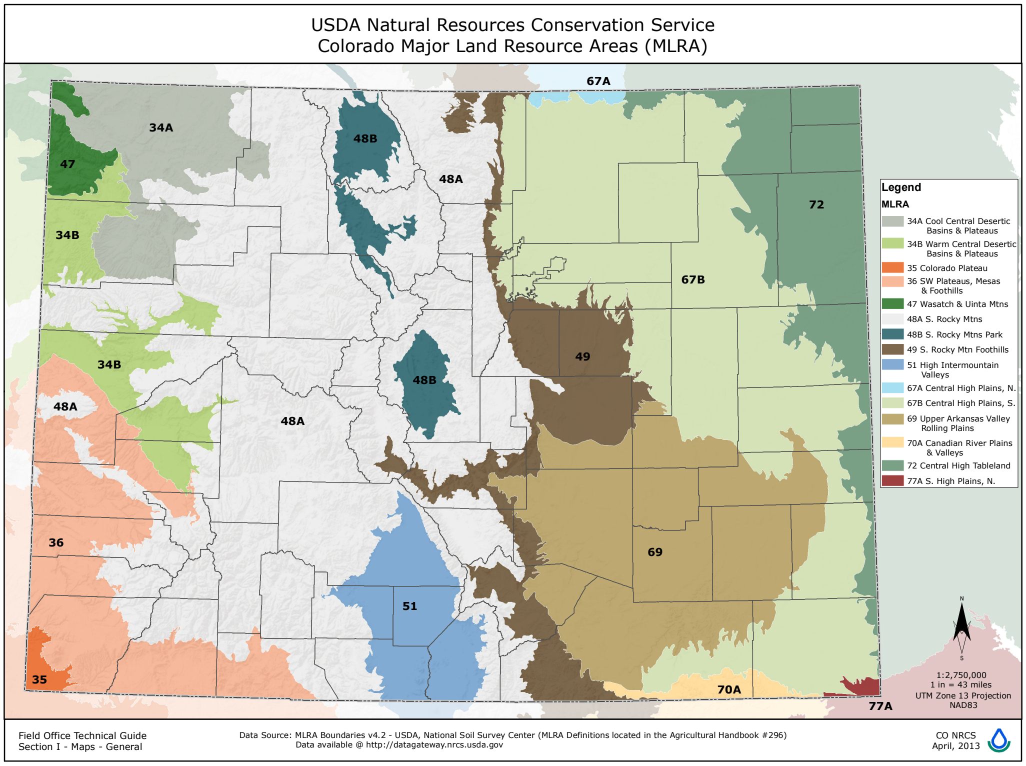

Figure 3: Major Land Resource Areas for the state of Colorado.

parameter γ allows for the impact of grazing pressure on forage potential to vary for different rangeland ecosystems (Milchunas and Lauenroth, 1993; George and Lile, 2009). In the simulation where we model grazing at the CPER, $\gamma = 1$. This parameterization follows the advice recommended by a team of ranching experts at the University of Wyoming who study the CPER.[4] They suggested that forage potential would decrease by 1-2% per year when grazing pressure is relatively high. If the range were less resilient to grazing pressure, γ would be less than 1, while those that are more resilient would have a value for γ that is greater than 1.

[4]The expert team consulted included Justin Derner, Dannele Peck, John Ritten, and John Hewlett.

Grazing pressure, G_t, depends on forage availability per cow-calf pair, λ_t, which depends on forage production of the rangeland, investment in drought adaptation, and herd size (see Section 3.3.1 for more details):

$$G_t = 1 - \lambda_t \tag{7}$$

At a sustainable equilibrium, $G_t = 0$. We define this equilibrium as follows: when forage availability per pair is equal to 1, then there is zero grazing pressure. As forage availability per pair falls below 1, then there is positive grazing pressure leading to a degradation of forage potential (Smart et al., 2010). As forage availability per pair rises above 1, then there is negative grazing pressure leading to a recovery of forage potential if it is not already at full health (Czeglédi and Radácsi, 2005), $\tilde{\alpha}$.

3.3 Flow Variables

3.3.1 Forage Availability

Forage availability per cow-calf pair is equal to the sum of forage production, F_t, and drought adaptation, a_t:

$$\lambda_t = F_t + a_t \tag{8}$$

Forage production per pair, F_t, is the dot product of forage potential, α_t, and monthly rainfall, ρ_t, divided by the ratio, $\%K$, of acres per cow and carrying capacity. α_t and ρ_t are vectors with a length of twelve representing each month of the year.

$$F_t = \frac{\alpha_t \cdot \rho_t}{\%K} \tag{9}$$

In an average rainfall year with undegraded forage potential, if the herd size is equal to the carrying capacity, then $F_t = 1$. As rainfall or forage potential increases (decreases), F_t increases (decreases). As herd size increases (decreases), F_t decreases (increases).

Utilization of carrying capacity, $\%K$, is defined as follows:

$$\%K = \frac{\frac{l}{\theta_t}}{K} \tag{10}$$

where l is the number of acres grazed, θ_t is the size of the herd (head of cows, not including calves or yearlings), and K is defined as the sustainable carrying capacity of the ranch in an average year (acres/cow).

When the herd is at its carrying capacity ($l/\theta_t = K$), $\%K = 1$. When the carrying capacity is exceeded, $\%K > 1$, which leads to a reduction of forage per pair, holding all else equal. In other words, at any given level of forage potential and rainfall, the forage per pair is smaller when the herd increases. Likewise, when $l/\theta_t < K$, the forage per pair increases (holding forage and rainfall constant).

Perfect adaptation, $\hat{a}_t$, is defined as the gap between full forage production per pair ($F_t = 1$) and actual forage production per pair—the percentage of total forage demand unmet by rangeland forage production.

$$\hat{a}_t = 1 - F_t \tag{11}$$

Actual adaptation, a_t, is defined as the portion of the gap between forage demand per pair and actual forage production per pair that is filled with drought adaptation measures. We define this as the ratio of expenditures on adaptation, $C(a_t)$, and cost of perfect adaptation, $C(\hat{a}_t)$, scaled by perfect adaptation, $\hat{a}_t$. We assume that the costs of adaptation are linear. The costs of adaptation are further discussed in section 3.3.3.

$$a_t = \frac{C(a_t)}{C(\hat{a}_t)}\hat{a}_t \tag{12}$$

3.3.2 Profit

Abstracting away from changes in herd assets (i.e., the value of cows), we consider the revenues to be cash flows in a given year and costs to be cash outlays in a given year:

$$\pi_t = R_t - C_t \tag{13}$$

There are four potential sources of revenues: calf sales, cow sales, earnings from interest on cash assets, and indemnities from rainfall-index insurance.

$$R_t = R_{\phi,t} + R_{\chi,t} + R_{interest,t} + R_{insurance,t} \tag{14}$$

There are four potential sources of costs: normal cow-calf operating costs, drought adaptation costs, interest on negative cash assets, and premiums for rainfall-index insurance.

$$C_t = C_{op,t} + C_{a,t} + C_{interest,t} + C_{insurance,t} \tag{15}$$

3.3.2.1 Calf Revenues

Calf revenues are a function of the price per pound for calves, $p_{\phi,t}$, the number of calves in the herd at the end of the growing season, ϕ, the average weaning weight of the calves in the herd, w_t, and the percentage of calves that are chosen to be sold, x_t.

$$R_{\phi,t} = p_{\phi,t} * \phi_t * w_t * x_t \tag{16}$$

In the simulation, calf prices are held constant at $p_\phi = \$1.40$ (Rutter et al., 2000a; Ishmael, 2018). The number of calves, ϕ_t, depends on the herd size, θ_t, and the weaning percentage at the end of the season, ω_t, (eq. 4).

$$\phi_t = \theta_t * \omega_t \tag{17}$$

Average weaning weight, w_t, is determined by forage availability, λ_t (eq. 8), and the maximum weaning weight, $\tilde{w}$.

$$w_t = \begin{cases} \tilde{w}\left(1 - \frac{(1-\lambda_t)}{3}\right) & \text{if } \lambda_t < 1 \\ \tilde{w} & \text{if } \lambda_t >= 1 \end{cases} \tag{18}$$

Average weaning weight, w, increases linearly with increasing forage availability to a maximum weight of $\tilde{w}$ (Scasta et al., 2015; Vantassell et al., 1987)[5]. In the simulation, $\tilde{w} = 600$ lbs. This is a simplified relationship that is more likely to reach an asymptotic maximum, however it roughly follows expectations based on market data and expert opinion.

3.3.2.2 Cow Revenues

Cow revenues are not dependent on weight as culled cows are assumed to be sold for a standard, per-cow price.

$$R_{\chi,t} = p_{\chi,t} * \theta_t * y_t \tag{19}$$

[5]Vantassell et al. 1987 states that "calf weights increased at a decreasing rate with respect to the amount of precipitation received." Based on previous literature that correlated a positive relationship between precipitation and forage, we can assume that weaning weight increases with forage availability to an asymptotic limit. The same applies to Scasta et al. 2016 - there is a correlation drawn between precipitation and weaning weight; for each inch reduction in rainfall, weaning weight decreases by 7-14 pounds

The price of cows in the simulation is held constant at \$850/cow (Ishmael, 2018).

3.3.2.3 Revenues

Insurance revenues are determined by the insurance policy parameters and the rainfall in insured months (USDA, 2015b).

In the simulation, the insured intervals are fixed at 50% for May-June and 50% for July-August. These four months are the most important for forage growth based on the forage production vector used in the simulation. These intervals were also chosen to coincide with an adaptation decision at the end of June, so players would be able to infer that they would likely have some indemnity payment but would not know the full extent of their likely payment.

To maximize the difference between the insured and non-insured treatment groups, we set the coverage level at the highest available point, which provides an indemnity when rainfall in the insured intervals falls below 90% of normal. Land productivity was set at 100%, representing an average level of productivity for rangelands.

Throughout the course of the simulation, payouts range between \$0 and \$38,076.

3.3.2.4 Normal Operating Costs

Normal operating costs increase at a constant rate with the number of cows in the herd (Lacey and Workman, 1986).[6] These operating costs include the cost of land, labor and other operating expenses other than insurance, drought adaptation, and interest on negative cash assets, which are modeled explicitly. Normal (non-drought) supplemental feed costs are also assumed to be included in this rate. Fixed operating costs, ζ, do not depend

[6]Although the total cost of production decreases with herd size, that we are only accounting for normal operating costs, not fixed costs.

on herd size.

$$C_{op,t} = c * \theta_t + \zeta \tag{20}$$

In the simulation, the per cow normal operating cost, c, is \$500 (Halich and Burdine, 2016; Lawrence and Strohbehn, 1999) and fixed costs, ζ, are \$0.[7]

3.3.3 Adaptation Costs

The actual costs of adaptation, $C(a_t)$, are chosen by the user. They choose the dollar amount of hay to purchase and that amount is translated into forage availability.

The costs of perfect adaptation are determined by the forage deficiency (or perfect adaptation level), $\hat{a}_t = (1 - F_t)$, herd size, θ_t, days of adaptation, δ_t, daily ration of hay for a cow-calf pair, q_h, and the price of hay, p_h. If forage production per pair is greater than 1, then additional forage is not needed and the costs of perfect adaptation is \$0.

$$C(\hat{a}_t) = \begin{cases} \hat{a}_t \theta_t \delta_t q_h p_h & \text{if } F_t < 1, \\ 0 & \text{if } F_t \geq 1 \end{cases} \tag{21}$$

In the simulation, the days of adaptation, δ_t, are fixed at 180 since the adaptation investment decision is made at the end of June with 180 days left in the year. The price of hay is fixed at $p_h = \$0.05$/pound. The daily hay ration is fixed at 22 pounds/day.

3.3.4 Insurance Costs

The insurance premium is based on the USDA Pasture, Rangeland, and Forage rainfall-index insurance rates from 2015 (USDA, 2015a). Insurance premiums are based on the number of acres grazed, not the herd size (USDA, 2015b). In the simulation, the ranch

[7] Our calculation of per cow normal operating costs is an average, based off of multiple sources

size is fixed at 3000 acres. The USDA PRF insurance is subsidized according to coverage level. At a 90% coverage level, the premium is 51% subsidized (USDA-RMA, 2017). With these variables set accordingly, the annual premium in the simulation is $5,655.

3.3.5 Interest Costs and Revenues

For simplicity, the interest rate on both positive and negative cash assets in the simulation is $r = 5\%$. In the simulation, players start with a positive cash asset balance of $90,000. We chose to start with a positive cash asset balance due to early feedback when participants noted that starting at zero made them very hesitant to go negative because of a personal aversion to debt. We seek to minimize this type of reference point dependent behavior by moving the reference point away from zero. The ability to accrue interest leads to discounting of earlier periods.

4 Methods

While experimental methods in economics research has become increasingly common (Latuszynkska, 2016) and simulations of risk and investment decisions have been used for decades in agriculture as a teaching tool (Anderson, 1974), their use as a research tool in agriculture has been more limited (Anderson et al., 1998). This study takes an innovative approach by pairing a coupled natural human systems model with a randomized control experiment with human subjects.

We recruited 610 participants from the online Amazon Mechanical Turk community. Of those initial participants, 540 completed the study (88% completion rate). The study population was exclusively from the United States with a geographically diverse sample yielding at least one participant from every state. The average age of the study population was approximately 35 years old, 61% of the population identified as male, and 81% of the population identified as white. Most of the sample had no prior knowledge of cattle ranching (79%) and only one person in the study population reported having worked on a cattle ranch before taking part in the study.[8]

To explain the experiment and the simulation, we provide participants with an instructional screencast that shows the practice simulation as it is run with a voiceover explaining the important information in each section. This ensures that everyone has a baseline of knowledge of how to operate the simulation and the cow-calf production system it represents. Where the simulations differ for the treatment and control groups, the screencast and explanations differ as well. Namely, the control group does not have any information about the rain-index insurance.

After the screencast, participants take a brief quiz to ensure that they comprehend the instructions and understand that the simulation and lottery game after the simulation are incentive compatible with real-world payoffs. When they successfully pass the comprehension quiz, they are directed to the DRIR-R simulation game hosted online.

In the insurance condition, participants are required to fully insure their range with rain-index insurance modeled closely after the USDA Pasture, Range and Forage insurance program. To maximize the response to the insurance, the coverage level is set at the most sensitive level: the insured participants receive indemnities when rainfall drops below 90% of the historical average for the insured intervals.[9] Under these policy parameters, the insurance premium is $5,655 per year. Participants in the insurance condition are required to pay the premium to continue each year in the simulation; they are required to manually type in the insurance premium each year, to ensure that they are conscious of the cost of the insurance premium. In the control condition, insurance for the ranch is not offered and

[8]See the Appendix for detailed demographic information broken down by treatment group.

[9]The productivity factor for the insurance is set at 100%, indicating that the range in the simulation has an average forage productivity. All 3000 acres in the simulated ranch are insured at 100% insurable interest.

cannot be purchased. Participants in the control condition are not told that the insurance is available.

First, participants complete a practice simulation. Their responses are recorded, but earnings in this round are not converted to an MTurk bonus payment. The practice simulation runs for five years. The simulation is run using historical rainfall for the grid that includes the Central Plains Experimental Research. The purpose of the practice round is to allow participants to learn what to expect in the simulation and to experiment with their decisions. Once they complete the practice rounds, they move on to the ten-year ranch simulation. Their previous decisions and outcomes from the practice round do not carry over to the paid simulation. The main difference between the practice round and full simulation is that the earnings in the full simulation are incentive compatible (the conversion rate and method is explained in further detail below). The practice round is also shorter, running five years instead of ten and the simulation runs historical rainfall from different time periods. The practice round pulls historical precipitation from 1951-1955 and the full simulation uses precipitation from 1999-2008. Both periods begin with a non-drought year and include a mix of drought and non-drought years.

Each year in the game is broken down into four sections: 1) Winter Ranch Report, 2) Summer Adaptation Investment Decision, 3) End of Growing Season Report, and 4) Fall Cow and Calf Sales (Figure 4).

In the Winter Ranch Report, participants take account of their herd, range health, and financial status. The game provides them with graphs of their net worth over the span of the simulation broken down into cash assets and herd assets and their range health over the span of the simulation as a percentage where 100% represents full health. They are also given information about their current herd size, the baseline operating costs for the coming year (which is dependent on herd size), and their personal annual expenses (which

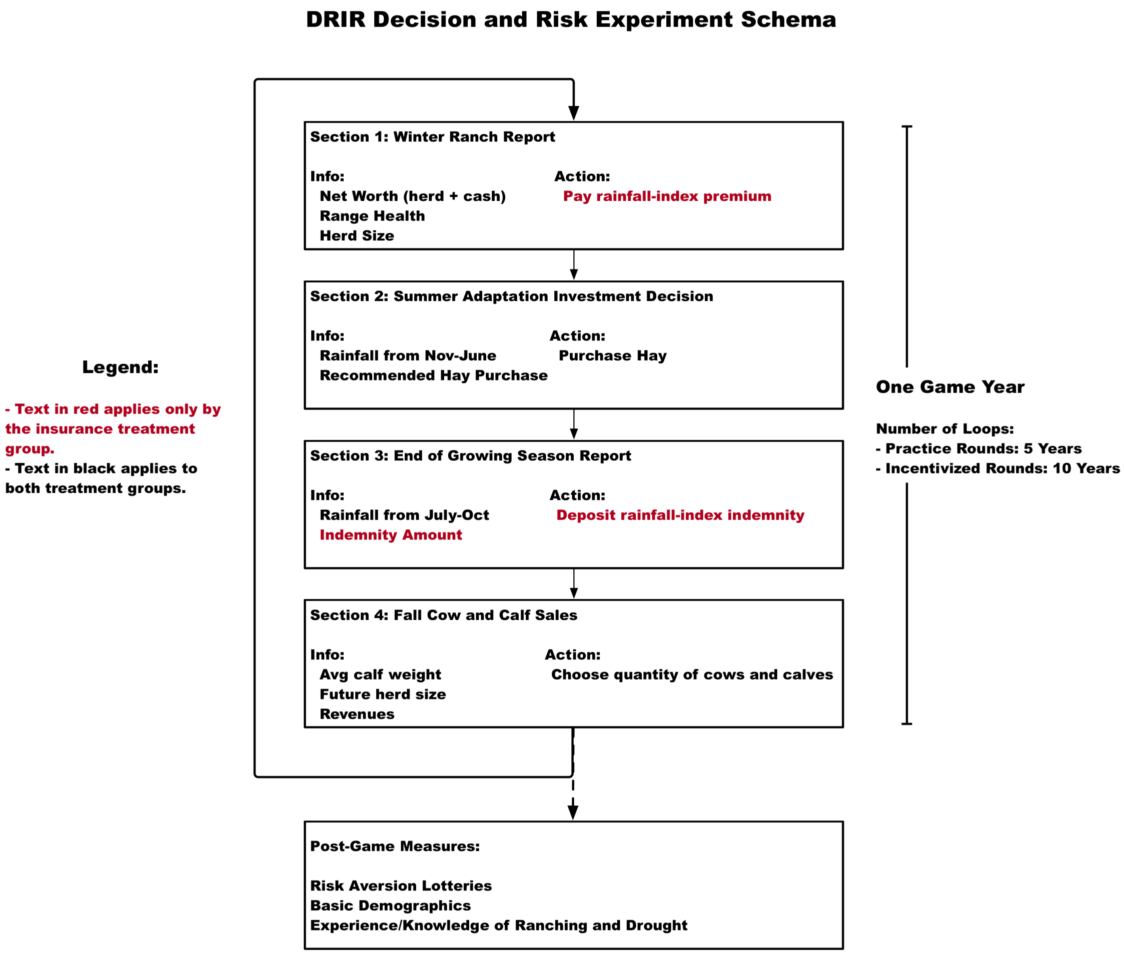

Figure 4: Graphical summary of one year in the DRIR game. Info indicates new information given in each section. Action indicates actions taken by the player.

is constant throughout the game and across all participants). For those in the insurance treatment, they are asked to "pay" their insurance premium by entering the amount due for the year. In the PRF rain-index insurance program, premiums must be paid before the primary growing season begins; the timing of the insurance bill reflects that.

In the Summer Adaptation Investment Decision, participants learn about how much rainfall they have had from November to June. This information is conveyed in graphical form along with information about historical averages for each month. They are also given a weighted average that is expressed as a percentage of normal rainfall for the growing season. Then they are given advice on how much hay they may want to buy for the rest of the year. The advice is broken down into optimal hay purchases for three different scenarios for rainfall in July through October: "normal" (average historical rainfall), "above average" (one standard deviation above the mean), and "below average" (one standard deviation below the mean). The amount of hay that is recommended in these scenarios depends on rangeland condition, rainfall from November to June, and herd size. Purchasing hay is the only adaptation in this model and participants cannot sell unused hay or carry over hay from year to year. Theoretically, the hay purchase represents any irreversible hedging investments that help buffer against low-rainfall and low per-cow-calf pair forage.

In the End of Growing Season Report, participants learn how much rain they had for July through October. For the insurance treatment, they also learn whether they received an insurance indemnity. If so, they are asked to type in the correct amount of the check to deposit it. Typing in the amount of both the premium and the indemnity helps increase the salience of the insurance policy for those in the insurance treatment.

In the Fall Cow and Calf Sales, participants learn about the average weight of the calves in their herd. If they are under the target weight of 600 pounds, they are told how much revenue they are missing out on due to the lack of weight gain. Calves are priced by weight at \$1.40 per pound. Cows are sold at a flat rate of \$850 per cow. In this section, participants decide how many cows and calves they will sell. They are given a graphical and numerical estimate of how their selling decisions in this section will affect their herd size for the next two years. Participants must sell at least half of their calves, because we assume that male calves have no economic value if kept in the herd.[10] Calves kept in the herd reach maturity and begin producing calves two years after they are born. As a simplifying assumption, we do not allow participants to sell yearlings (calves that are one year old). They also do not add to the forage demand or operating costs. Generally, cow-calf producers sell any cows that do not produce calves in any given year. This keeps the productivity rate of the herd high. Given that our optimal calving rate is 88%, if at least 12% of cows are not sold, then the birth rate of their herd the following year will be diminished.[11] Participants are also reminded that the carrying capacity of their ranch is 600 cows and having a larger herd may damage their range health and decrease grass production. Finally, participants are given the revenues they will earn for the cow and calf sales numbers they have selected. Participants can change the number of cows and calves they may sell and watch the future herd size and revenues respond in real time. Once they are satisfied with their sales choices, they lock in the sales and move to the next year in the simulation.

During the practice round, this four-section cycle repeats for five years. During the simulation that counts, this cycle repeats for ten years. At the end of those ten years, participants' earnings are translated into their real-world MTurk bonus payment. Participants' payment is determined by their ending net worth after ten years minus their initial net worth at the beginning of the ten-year simulation. This number is divided by \$50,000.

[10]The exception to this general rule is if male calves are kept on the range for another season to be sold at a higher weight. However, this is an uncommon cow-calf production strategy, so we do not allow it in this game.

[11]See Section 3 for further details.

If their net worth does not increase over ten years from the initial amount, then they do not get an MTurk bonus for the simulation.

After completing the game, participants choose between a series of lotteries designed to generate a measure of risk aversion (Holt and Laury, 2002). The lottery choices are incentive compatible—ten randomly chosen participants have one randomly selected lottery choice implemented and receive a second MTurk bonus according to their lottery payoffs.

Finally, participants answer a number of demographic questions. There are also a few questions specific to ranching and drought. We ask about their general level of knowledge and first-hand experience with ranching and drought. We also inquire about political voting preferences, identification as an environmentalist, and whether they are vegan or vegetarian. Additionally, we include two questions that measure whether they are paying attention to the text of the questions. If they incorrectly answer both questions, they are removed from the sample.

5 Results

5.1 Herd Size

One of the primary hypotheses of this study was that the presence of the insurance policy would lead to increased herd sizes. The online experiment results do not support this hypothesis. Using a generalized linear mixed model with a Poisson distribution with individual random effects, I find no impact of insurance on herd size ($\beta_{ins} = -0.013, p = 0.523$). These findings are robust to a number of different model specifications (Table 1 and Appendix).

The level of risk aversion of the participant, measured after the experiment in an incentive compatible lottery choice (Holt and Laury, 2002), correlates with the participant's

Table 1: Impact of Insurance on Herd Size

	Dependent variable:		
	Herd Size		
	(1)	(2)	(3)
Insurance	−0.013	−0.013	−0.013
	(0.029)	(0.019)	(0.020)
Herd_{t-1}		0.001^{***}	0.001^{***}
		(0.00001)	(0.00001)
Herd_{t-2}		0.0002^{***}	0.0004^{***}
		(0.00001)	(0.00001)
Constant	6.279^{***}	5.523^{***}	5.591^{***}
	(0.020)	(0.014)	(0.014)
Year Fixed Effects	No	No	Yes
Observations	5,440	5,440	5,440
Log Likelihood	−127,758.300	−102,135.000	−89,032.600
Akaike Inf. Crit.	255,522.600	204,279.900	178,093.200
Bayesian Inf. Crit.	255,542.400	204,312.900	178,185.600
Note:	*p<0.1; **p<0.05; ***p<0.01 GLMM model with a Poisson distribution and individual random effects.		

herd size. A one standard deviation increase in risk aversion leads to a 2.0% increase in the annual size of the herd ($p = 0.016$). With a median herd size of 600 cows, this corresponds to an increase of about 12 cows. I also tested and found no interaction effect between insurance and risk aversion ($p = 0.9887$).

Table 2: Impact of Risk Aversion on Herd Size

	Dependent variable:		
	Herd Size		
	(1)	(2)	(3)
Insurance	0.003	0.0001	0.0002
	(0.025)	(0.017)	(0.017)
Risk Aversion	0.030**	0.020**	0.020**
	(0.013)	(0.008)	(0.008)
Herd_{t-1}		0.001***	0.001***
		(0.00001)	(0.00001)
Herd_{t-2}		0.0001***	0.0003***
		(0.00001)	(0.00001)
Constant	6.293***	5.611***	5.657***
	(0.018)	(0.012)	(0.013)
Year Fixed Effects	No	No	Yes
Observations	4,950	4,950	4,950
Log Likelihood	−110,916.000	−90,702.290	−79,047.960
Akaike Inf. Crit.	221,840.000	181,416.600	158,125.900
Bayesian Inf. Crit.	221,866.000	181,455.600	158,223.500
Note:	*p<0.1; **p<0.05; ***p<0.01 GLMM model with a Poisson distribution and individual random effects.		

To explore whether the relationship between risk aversion and herd size could be due to differences in overall strategy, such as choosing to completely liquidate the herd or grow the herd far beyond the recommended carrying capacity, I carry out a series of logistic regressions.

Overall, only 38 of the 544 online participants chose to liquidate their herd (6.7%). To find out if there is a relationship between the likelihood of shutting down an active ranching operation in the simulation and the insurance treatment or risk aversion, I regress a binary variable that indicates whether the participant liquidated their herd at any point in the simulation on an insurance treatment indicator, standardized risk aversion, and an interaction term in a logistic regression model (Table 3). For all levels of risk aversion, insurance significantly reduces the likelihood of liquidating one's herd ($p = 0.0368$). The interaction between the insurance treatment and the risk aversion coefficient is also significant indicating that those who are more risk averse and insured are even less likely to liquidate their herd than those who are less risk averse ($p = 0.0309$).

Only 9 out of 544 participants increased their herd size above 1200, twice the recommended carrying capacity. To analyze this behavior, I regress a binary variable that indicates that the participant grew the herd to more than double the carrying capacity of the ranch on an insurance treatment indicator, standardized risk aversion, and an interaction term in a logistic regression model (Table 3). The insurance treatment and risk aversion do not have an independent effect on the likelihood of going for a large herd strategy. However, the interaction between insurance and risk aversion is statistically significant ($p = 0.002$). This indicates that those who are insured and more risk averse are less likely to pursue an extremely large herd strategy.

To test whether these strategies alone could be responsible for the relationship between risk aversion and herd size, I also run regressions similar to Table 1 and 2 but with these extreme cases excluded. First I use the cutoff of 1200 cows in a herd and exclude all obser-

Table 3: Impact of Insurance and Risk Aversion on Liquidation and Extreme Herd Size

	Dependent variable:			
	Liquidated Herd		Large Herd	
	(1)	(2)	(3)	(4)
Insurance	-0.211^{*}	-0.256^{**}	0.087	-0.012
	(0.125)	(0.127)	(0.226)	(0.234)
Risk Aversion	-0.211^{***}	-0.128^{*}	-0.171^{*}	0.131
	(0.055)	(0.072)	(0.102)	(0.165)
Ins X Risk		-0.217^{*}		-0.591^{***}
		(0.112)		(0.214)
Constant	-2.739^{***}	-2.721^{***}	-4.167^{***}	-4.147^{***}
	(0.083)	(0.083)	(0.161)	(0.160)
Observations	4,950	4,950	4,950	4,950
Log Likelihood	$-1,067.465$	$-1,065.606$	-407.996	-403.985
Akaike Inf. Crit.	2,140.931	2,139.211	821.991	815.970
Note:				*p<0.1; **p<0.05; ***p<0.01
				Logistic regression model

vations from any participant that exceeded this limit at any point during the simulation. Excluding the right tail of the distribution cuts the effect of risk aversion on herd size in half, but the relationship is marginally significant ($\beta_{risk} = 0.010, p = 0.071$). When all participants who liquidate their herd at some point in the simulation are excluded, the effect of risk aversion also decreases, but by a smaller amount ($\beta_{risk} = 0.014, p = 0.007$). When both those with extremely large herds and those who liquidated their herds are excluded, the impact of risk on herd size is small, but statistically significant ($\beta_{risk} = 0.008, p = 0.012$). This general pattern is robust to smaller cutoff points for a large herd of up 800 cows after which decreasing the cutoff further weakens the effect.

These sensitivity analyses indicate that part of the impact of risk aversion on herd size is due to extreme behavior, but that the relationship is robust even when only moderate values are included in the analysis. Thus we can conclude that those who are more risk averse are less likely to liquidate their herd or grow their herd to extreme sizes, but that even when those who exhibit these extreme behaviors are excluded, increased risk aversion correlates the tendency to maintain slightly larger herds.

5.2 Hay Purchase

The second primary hypothesis in this study was that the presence of insurance would affect the investment in supplemental feed. The rationale for this hypothesis lies in the fact that the rain-index insurance changes the returns to investment in both risky and hedging inputs (Karlan et al., 2014). In formulating the model and the hypothesis, I assumed that purchasing hay would be viewed as a hedge against low rainfall. With low rainfall, forage production from the range would be insufficient to meet the nutritional needs of the herd which would lead to lower productivity. However, with high rainfall, the hay would not be needed and the investment would not yield positive marginal revenues.

Therefore, I expected that the presence of insurance would reduce investment in hay.

However, the results from the online experiment indicate a different story. After controlling for herd size and cash assets on hand at the time of the hay purchase, insurance increases the investment in supplemental hay ($p = 0.0275$). The relationship between insurance treatment and amount of hay purchased is positive under all model specifications explored. This leads to a clear rejection of H2.

The impact of risk aversion interacts with the insurance treatment to produce opposite effects for those with and without insurance. Those in the insurance treatment with higher levels of risk aversion tend to buy more hay than those with lower levels of risk aversion in the insurance treatment ($p = 0.0504$, Table 4). The opposite is true for those in the no insurance treatment; higher levels of risk aversion are associated with purchasing less hay than those with lower levels of risk aversion ($p = 0.0252$, Table 4).

A similar pattern holds for men in the insurance and no insurance treatments; men in the insurance treatment buy more hay than women in the insurance treatment, although the result is marginally significant ($p = 0.0902$), and men in the no insurance treatment buy less hay than women in the no insurance treatment ($p = 0.0086$). As in many other studies, men tend to be less risk averse than women ($p < 0.001$ in a single variable regression of a male indicator variable on the experimental measure of risk aversion). After controlling for gender and its interaction with the insurance treatment, the relationship between risk aversion and insurance treatment is still significant. Thus, gender does not explain the relationship, it only enforces the finding that the insurance treatment affects the supplemental feed investment decision differentially depending on risk aversion levels.

The results also show that larger cash assets are associated with less spending on supplemental feed ($p < 0.001$). It is likely that the causal direction is from tendency to purchase hay to lower cash assets. Those who purchase too much hay will have lower cash assets because their marginal expenditures on hay are greater than the marginal revenue of the hay purchase.

The relationship between risk aversion and hay investment provides evidence that the MTurk study population did not view hay as a hedging input against low rainfall in the way that I expected. Those who are risk averse purchase more hay when they have insurance, but less hay when they do not have insurance. This indicates the possibility that hay is viewed, by this study population, as a risky input not as a hedging input.

5.3 Net Worth

The insurance treatment led to a higher net worth after the ten-year simulation compared to the no insurance treatment. The insurance treatment was associated with an increase in net worth of \$74,937 ($p < 0.001$). Once the net wealth transfer of the insurance policy was subtracted from the net worth, the insurance treatment showed an ending net worth \$12,105 higher than the no insurance treatment, but the difference between the groups was insignificant ($p = 0.404$).

Risk aversion played a major role in the success of participants in the ranching simulation. An increase in risk aversion by one standard deviation was associated with a ten-year gain in net worth of \$24,433 ($p < 0.001$). This result is robust to other demographic characteristics of each participant. There was a positive, but insignificant interaction effect between risk aversion and insurance treatment ($p = 0.5331$), which indicates that the insurance treatment did not differentially impact the net earnings of risk averse participants compared to those who were less risk averse.

Table 4: Impact of Insurance and Risk Aversion on Hay Purchase

	Dependent variable:				
	Hay Purchase				
	(1)	(2)	(3)	(4)	(5)
Insurance	1.227	2.580**	2.575**	2.560**	2.605**
	(1.176)	(1.168)	(1.206)	(1.203)	(1.288)
Herd Size	0.075***	0.057***	0.060***	0.060***	0.063***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Cash Assets		−0.049***	−0.053***	−0.054***	−0.053***
		(0.003)	(0.004)	(0.004)	(0.004)
Risk Aversion			−0.767	−1.769**	−1.766**
			(0.601)	(0.788)	(0.837)
Ins X Risk				2.380**	2.150*
				(1.213)	(1.299)
Constant	−45.466***	−31.134***	−32.297***	−32.292***	−30.919***
	(2.024)	(2.221)	(2.338)	(2.337)	(3.859)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Demographics	No	No	No	No	Yes
Observations	5,990	5,990	5,430	5,430	5,013
Log Likelihood	−28,126.450	−28,027.180	−25,366.780	−25,363.750	−23,468.560
Note:	*p<0.1; **p<0.05; ***p<0.01 Mixed effects model with individual random effects.				

Table 5: Impact of Insurance and Risk Aversion on Gains in Net Worth

	Dependent variable:			
	Change in Net Worth After Ten Year Simulation			
	(1)	(2)	(3)	(4)
Insurance	74,937.120***	70,654.820***	69,188.730***	70,655.780***
	(14,505.670)	(13,891.780)	(14,938.240)	(13,900.560)
Risk Aversion		24,432.760***	22,320.040***	20,763.540**
		(6,924.730)	(7,365.392)	(9,089.862)
Ins X Risk				8,758.856
				(14,044.120)
Constant	38,357.470***	55,502.980***	−36,314.430	55,317.670***
	(10,004.240)	(9,647.322)	(169,612.400)	(9,657.990)
Demographics	No	No	Yes	No
Observations	534	487	449	487
Adjusted R^2	0.046	0.072	0.054	0.071

Note: *p<0.1; **p<0.05; ***p<0.01

6 Conclusions

This paper presents the DRIR-R model, the first decision model to include the new USDA PRF rain-index insurance. DRIR-R is a coupled natural-human systems dynamic optimization model of cow-calf production on a northeastern Colorado range. Using the DRIR-R model, we built a user interface that allows us to run randomized control experiments that put real people instead of optimization criteria in the central role as decision-makers. I tested this model with a non-rancher population recruited online through Amazon MTurk. The experiment tested two primary hypotheses:

H1: The availability of rain-index insurance leads to increases in the average size of cattle herds because the expected return on investment in cattle production will increase when drought risk is mitigated.

H2: The availability of rain-index insurance will decrease investment in (i.e., crowd-out) other drought adaptation strategies because insurance serves as a substitute.

Both hypotheses were definitively rejected. Insurance had no impact on average herd size, although it did reduce the tendency to liquidate the herd. This indicates that, in this scenario, the rain-index insurance may affect the extensive margin rather than the intensive margin of cow-calf production. In other words, insurance may encourage entry into the cow-calf production market or discourage exit. If this trend holds in a real-world market scenario, then the rain-index insurance could lead to an expansion of ranching. This could have implications for regions with marginal lands that may be sensitive to the stress of grazing, especially under drought or a warmer climate.

Insurance had a positive impact on investment in supplemental feed. This positive relationship was amplified for participants with higher levels of risk aversion. This calls into question the assumption that hay purchase is treated as a hedging input by the study population. Combined with the finding that insurance only had an impact on herd size through extreme behavior such as liquidating the herd or greatly increasing the size of the herd, it is likely that participants in the simulation viewed the hay purchase as the primary input for cow-calf production rather than herd size. The more complex relationship between cow and calf sales and herd size plus the warning that exceeding to carrying capacity would lead to declines in rangeland productivity may have led many participants to think of herd size as more or less fixed.

These results may be population dependent: those with experience and knowledge of ranching may behave quite differently. Further studies that will employ real-world ranchers as participants are crucial to understanding the impacts of rain-index insurance on cow-calf production and subsequent impacts on land use and drought resilience. I am currently working with the USDA North Central Climate Hub and the Central Plains Experimental Range to plan experiments with ranchers using the DRIR-R simulation. These studies will likely yield new insights that will clarify and deepen these unexpected, but highly interesting preliminary results.

References

How Does Your Herd Measure Up?, 2002. URL https://www.noble.org/news/publications/ag-news-and-views/2002/november/how-does-your-her

W. Neil Adger. Vulnerability. *Global Environmental Change*, 16(3):268–281, 2006. ISSN 09593780. doi: 10.1016/j.gloenvcha.2006.02.006.

Syed M Ahsan, Ali A G Ali, and N John Kurian. Toward a Theory of Agricultural Insurance. *American Journal of Agricultural Economics*, 64(3):520–529, 1982.

Jock R. Anderson. Simulation: Methodology and Application in Agricultural Economics. *Review of Marketing and Agricultural Economics*, 42(1):3–55, 1974. URL http://econpapers.repec.org/article/agsremaae/9675.htm.

John D Anderson, Clement E Ward, Stephen R Koontz, Derrell S Peel, and James N Trapp. Experimental Simulation of Public Information Impacts on Price Discovery and Marketing Efficiency in the Fed Cattle Market. *Journal of Agricultural and Resource Economics*, 23(1):262–278, 1998.

Francis Annan and Wolfram Schlenker. Federal Crop Insurance and the Disincentive to Adapt to Extreme Heat. *American Economic Review: Papers & Proceedings*, 105(5): 262–266, 2015. ISSN 0002-8282. doi: 10.1257/aer.p20151031.

John M. Antle. Climate Change and Agriculture: Economic Impacts. *Choices*, 23:9–11, 2008.

Toby R. Ault, Julia E. Cole, Jonathan T. Overpeck, Gregory T. Pederson, and David M. Meko. Assessing the risk of persistent drought using climate model simulations and paleoclimate data. *Journal of Climate*, 27(20):7529–7549, 2014. ISSN 08948755. doi: 10.1175/JCLI-D-12-00282.1.

B J Barnett. US government natural disaster assistance: historical analysis and a proposal for the future. *Disasters*, 23(2):139–155, 1999. ISSN 1467-7717. doi: 10.1111/1467-7717.00110.

BJ Barnett. The US federal crop insurance program. *Canadian Journal of Agricultural Economics/Revue . . .*, 2000. URL `http://onlinelibrary.wiley.com/doi/10.1111/j.1744-7976.2000.tb00409.x/abstract`.

T. M. Brown-Brandl, R. A. Eigenberg, and J. A. Nienaber. Heat stress risk factors of feedlot heifers. *Livestock Science*, 105(1-3):57–68, 2006. ISSN 18711413. doi: 10.1016/j.livsci.2006.04.025.

Raymond J. Burby. Flood insurance and floodplain management: The US experience. *Environmental Hazards*, 3(3-4):111–122, 2001. ISSN 14642867. doi: 10.1016/S1464-2867(02)00003-7.

Dwight R. Cable. Influence of Precipitation on Perennial Grass Production in the Semidesert Southwest. *Ecology*, 56(4):981–986, 1975.

Hongbin Cai, Yuyu Chen, Hanming Fang, and Li-An Zhou. The effect of microinsurance on economic activities: evidence from a randomized field experiment. *The Review of Economics and Statstics*, 97(2):287–300, 2015. ISSN 1725-2806. doi: 10.1162/REST.

Jing Cai. The Impact of Insurance Provision on Households' Production and Financial Decisions. *Munich Personal RePEc Archive, Working Paper*, (No. 46864), 2013. ISSN 03014215. doi: 10.5897/JAERD12.088.

Michael R. Carter, Lan Cheng, and Alexandros Sarris. Where and how index insurance can boost the adoption of improved agricultural technologies. *Journal of Development Economics*, 118:59–71, 2016. ISSN 03043878. doi: 10.1016/j.jdeveco.2015.08.008.

Keith H. Coble and Barry J. Barnett. Why do we subsidize crop insurance? *American Journal of Agricultural Economics*, 95(2):498–504, 2012. ISSN 00029092. doi: 10.1093/ajae/aas093.

Keith H. Coble and Thomas O Knight. Crop Insurance as a Tool for Price and Yield Risk Management. In Richard Just and Rulon Pope, editors, *Comprehensive Assessment of the Role of Risk in U.S. Agriculture*. Kluwer Publishers, 2002.

Shawn Cole, Xavier Giné, Jeremy Tobacman, Petia Topalova, Robert Townsend, and James Vickery. Barriers to household risk management: Evidence from India. *IMF Working Paper*, 5(1):104–135, 2013. ISSN 19457782. doi: 10.1596/1813-9450-5504. URL `http://elibrary.worldbank.org/doi/book/10.1596/1813-9450-5504%5Cnhttp://www.ncbi.nlm.nih.`

John Comerford. Reproduction by the Numbers, 2017. URL `extension.psu.edu/reproduction-by-the-numbers`.

John W. Comerford. Beef Cow-Calf Production, 2018. URL `extension.psu.edu/beef-cow-calf-production`.

Julie Conley, Hallie Eakin, Thomas E Sheridan, and Diana Hadley. CLIMAS Ranching Case Study : Year 1. Technical report, Climate Assessment for the Southwest, University of Arizona, 1999.

Benjamin I Cook, Toby R Ault, and Jason E Smerdon. Unprecedented 21st century drought risk in the American Southwest and Central Plains. *Science Advances*, 1 (1):e1400082–e1400082, 2015. ISSN 2375-2548. doi: 10.1126/sciadv.1400082. URL http://advances.sciencemag.org/content/advances/1/1/e1400082.full.pdf http://advances.sciencemag.org/cgi/doi/10.1126/sciadv.1400082.

Levente Czeglédi and Andrea Radácsi. Overutilization of Pastures by Livestock. *Grassland Studies*, 3:29–35, 2005.

A G Dai. Increasing drought under global warming in observations and models. *Nature Climate Change*, 3(1):52–58, 2013. ISSN 1758-678X. doi: 10.1038/nclimate1633.

Russell Daly. When should we give colostrum and what should we use?, 2012.

Justin Derner, David Briske, Matt Reeves, Tami Brown-Brandl, Miranda Meehan, Dana Blumenthal, William Travis, David Augustine, Hailey Wilmer, Derek Scasta, John Hendrickson, Jerry Volesky, Laura Edwards, and Dannele Peck. Vulnerability of grazing and confined livestock in the Northern Great Plains to projected mid- and late-twenty-first century climate. *Climatic Change*, pages 1–14, 2017. ISSN 15731480. doi: 10.1007/s10584-017-2029-6. URL http://link.springer.com/10.1007/s10584-017-2029-6.

Avinash K. Dixit and Robert S. Pindyck. *Investment Under Uncertainty*. Princeton University Press, 1994. ISBN 9788578110796. doi: 10.2307/1909571. URL https://msuweb.montclair.edu/ lebelp/DixitPindyck1994.pdf http://www.jstor.org/stable/1909571?origin=crossref.

Xiaodong Du, Hongli Feng, and David A. Hennessy. Rationality of Choices in Subsidized Crop Insurance Markets. *American Journal of Agricultural Economics*, 99(3):732–756, 2016. ISSN 0002-9092. doi: 10.1093/ajae/aaw035. URL https://academic.oup.com/ajae/article-lookup/doi/10.1093/ajae/aaw035.

Dan E. Eversole, Milysssa F. Browne, John B. Hall, and Richard E. Dietz. Body Condition Scoring Beef Cows. *Virgina Cooperative Extension, 400-791*, pages 1 – 7, 2009.

A. Fall, M. Diop, J. Sandford, Y.J. Wissocq, J.W. Durkin, and J.C.M. Trail. Evaluation of the productivities of Djallonke sheep and N'Dama cattle at the Centre de Recherches Zootechnique,(Kolda,Senegal), ILCA Research Report. *ILCA*, (3):79, 1982.

Samuel Fankhauser, Joel B. Smith, and Richard S.J. Tol. Weathering climate change: Some simple rules to guide adaptation decisions. *Ecological Economics*, 30(1):67–78, 1999. ISSN 09218009. doi: 10.1016/S0921-8009(98)00117-7.

Farmland Information Center. 2012 Census of Agriculture, 2014. URL `farmlandinfo.org/2012-census-agriculture`.

Scott Fausti, Brad Johnson, William Epperson, Scott W Fausti, Brad Johnson, William Epperson, and Nancy Grathwohl. Risk and Economic incentive to Retain Ownership of Steer Calves. 2003. URL `http://openprairie.sdstate.edu/econ_staffpaper` `http://openprairie.sdstate.edu/econ_staffpaper/171`.

Philip A. Fay, Jonathan D. Carlisle, Alan K. Knapp, John M. Blair, and Scott L. Collins. Productivity responses to altered rainfall patterns in a C 4-dominated grassland. *Oecologia*, 137(2):245–251, 2003. ISSN 00298549. doi: 10.1007/s00442-003-1331-3.

Kelsey Frasier Pope, Ted C Schroeder, Michael R Langemeier, and Kevin L Herbel. Cow-Calf Producer Risk Preference Impacts on Retained Ownership Strategies. *Agricultural and Applied Economics*, 43(497-513), 2011. URL `http://ageconsearch.tind.io/record/117953/files/jaae437-Pope.pdf`.

G.B. Frisvold, L. E. Jackson, J. G. Pritchett, and J.P Ritten. Agriculture and Ranching. Technical report, Southwest Climate Alliance, Washington, DC, 2013.

Alan Fuchs, Hendrik Wolff, Alan Fuchs, and Hendrik Wolff. Concept and Unintended Consequences of Weather Index Insurance : The Case of Mexico. *IZA*, (6234), 2011.

Melvin George and David Lile. Stocking Rate and Carrying Capacity. Technical report, 2009.

Carey Gillam. Ranchers, Farmers Seek Solution to Water Worries, jul 2012. URL `http://northernag.net/AGNews/AgNewsStories/TabId/657/ArtMID/2927/ArticleID/2370/Ranchers-`

B Godfrey, J Parsons, J Deering, and D Hoag. Bar BQ Ranch. (October):0–4, 2009.

G. L. Hahn. Dynamic responses of cattle to thermal heat loads. *Journal of animal science*, 77 Suppl 2(1989):10–20, 1999. ISSN 00218812. doi: 10.2527/1997.77suppl$_2$10x.

Greg Halich and Kenny Burdine. Kentucky Proud Cow-calf profitability expectations for fall 2016, 2016.

Charles A Holt and Susan K Laury. Risk Aversion and Incentive Effects. *American Economic Review*, 92(5):1644–1655, 2002.

H. N. Le Houerou and C. H. Hoste. Rangeland Production and Annual Rainfall Relations in the Mediterranean Basin and in the African Sahelo-Sudanian Zone. *Journal of Range Management*, 30(3):181–189, 1977. ISSN 0022409X. doi: 10.2307/3897463. URL `http://www.jstor.org/stable/3897463?origin=crossref`.

Wes Ishmael. CattleFax Outlook : Cattle profitability remains for 2018, 2018.

R.C. Izaurralde, A.M. Thomson, J.A. Morgan, P.A. Fay, H.W. Polley, and JL Hatfield. Climate impacts on agriculture: implications for crop production. *Agronomy Journal*, 103(2):371–381, 2011. ISSN 00021962. doi: 10.2134/agronj2010.0303. URL `https://www.agronomy.org/publications/aj/abstracts/103/2/351%5Cnhttps://dl.sciencesocieties`

Richard E Just, Linda Calvin, and John Quiggin. Adverse Selection in Crop Insurance: Actuarial and Asymmetric Information Incentives. *American Journal of Agricultural Economics*, 811861(4):834–849, 1999. ISSN 00029092. doi: 10.2307/1244328. URL `http://www.jstor.org/stable/1244328%5Cnhttp://www.jstor.org/stable/1244328`.

Dean Karlan, Robert Osei, Isaac Osei-akoto, and Christopher Udry. Agricultural Decisions After Relaxing Credit and Risk Constraints. *Quarterly Journal of Economics*, 129(2): 597–652, 2014. ISSN 0033-5533. doi: doi.org/10.1093/qje/qju002.

Alan K Knapp, Christopher W Harper, Brett T Danner, and Michelle S Lett. Rainfall Variability, Carbon Cycling, and Plant Species Diversity in a Mesic Grassland. *Science*, 298(2002):2202–2205, 2002. ISSN 00368075. doi: 10.1126/science.1076347.

Daniel M. Kniffen. Colostrum and Calf Productivity: A Review Recent. Technical report.

Howard Kunreuther. Mitigating disaster losses through insurance. *Journal of Risk and Uncertainty*, 12(2-3):171–187, 1996. ISSN 08955646. doi: 10.1007/BF00055792. URL `http://www.scopus.com/inward/record.url?eid=2-s2.0-21344466340&partnerID=tZOtx3y1`.

John R Lacey and John P Workman. A Comparison of Average Variable Costs of Private vs . Public Land Ranches in Southeastern Montana. *Journal of Range Management*, 39(4): 290–292, 1986.

Malgorzata Latuszynkska. Experimental Research in Economics and Computer Simulation. In K Nermen and M Latuszynska, editors, *Selected Issues in Experimental Economics*, pages 151–169. 2016. ISBN 9783319284194. doi: 10.1007/978-3-319-28419-4.

John D. Lawrence and Daryl R. Strohbehn. Understanding and Managing Costs in Beef Cow-Calf Herds. *Iowa Beef Center*, 1999.

JW Longworth and WJ McLeland. Economies of Size in Wheat Production. *Review of Marketing and ...*, pages 1–4, 1972. URL http://ageconsearch.umn.edu/bitstream/9617/1/40020053.pdf.

K P McNew, Harry P Mapp, Claude E Duchon, and Earl S Merritt. Sources and Uses of Weather Information for Agricultural Decision Makers. *Bulletin of the American Meteorological Society*, 72(4):491–498, 1991. doi: 10.1175/1520-0477(1991)072¡0491:SAUOWI¿2.0.CO;2.

Jerry M Melillo, Terese (T.C.) Richmond, and Gary W. Yohe. Climate Change Impacts in the United States: The Third National Climate Assessment. Technical report, Washington, DC, 2014.

D G Milchunas and W K Lauenroth. Quantitative effects of grazing on vegetation and soils over a global range of environmnents. *Ecological Monographs*, 63(4):327–366, 1993. ISSN 00129615. doi: 10.2307/2937150. URL papers2://publication/uuid/F92D3D63-CFA1-41D9-9AA4-0743A323A016.

Philipe Moriel. Fetal Programming : Cow Nutrition and its Effects on Calf Performance. Technical report, NC State Extension, 2016.

Eric Morignat, Jean Baptiste Perrin, Emilie Gay, Jean Luc Vinard, Didier Calavas, and Viviane Hénaux. Assessment of the impact of the 2003 and 2006 heat waves on cattle mortality in France. *PLoS ONE*, 9(3), 2014. ISSN 19326203. doi: 10.1371/journal.pone.0093176.

James B. Neel. Feeding poor quality hay results in poor performance by:- Drovers undefined, 2011.

H. Wayne Polley, David D. Briske, Jack A. Morgan, Klaus Wolter, Derek W. Bailey, and Joel R. Brown. Climate Change and North American Rangelands:

Trends, Projections, and Implications. *Rangeland Ecology & Management*, 66 (5):493–511, 2013. ISSN 15507424. doi: 10.2111/REM-D-12-00068.1. URL `http://linkinghub.elsevier.com/retrieve/pii/S1550742413500595`.

John Roy Porter, Liyong Xie, Andrew J. Challinor, Kevern Cochrane, S. Mark Howden, Muhammed Mohsin Iqbal, David B. Lobell, and Maria Isabel Travasso. Food Security and Food Production Systems. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, chapter Chapter 7, pages 485–533. Cambridge University Press, 2014.

Richard Randle. When Should Colostrum Replacement Products Be Used for Newborn Calves ? Colostrum replacement products, 2015.

Mike Rankin. Today's pastures are tomorrow's calves, 2017.

Matt C. Reeves and Karen E Bagne. Vulnerability of cattle production to climate change on U.S. rangelands. Technical Report May, USDA, Fort Collins, 2016.

Laura Rutter, Dale Engstrom, and Rob Hand. 2017 Cattle Outlook: Prices Haven't Hit the Bottom, 2000a.

Laura Rutter, Dale Engstrom, and Rob Hand. Body Condition: Implications for Managing Beef Cows. *Alberta Ag-Info Centre: Agri-Facts*, (Figure 1):1–9, 2000b. URL `www.agric.gov`.

John D. Scasta, Jessica L. Windh, Travis Smith, and Bob Baumgartner. Drought consequences for cow-calf production in Wyoming: 2011-2014. *Rangelands*, 37(5):171–177, 2015. ISSN 1551501X. doi: 10.1016/j.rala.2015.07.001.

Ted C Schroeder and Allen M Featherstone. Dynamic marketing and retention decisions for cow-calf producers. *American Journal of Agricultural Economics*, 72(4):1028, 1990. ISSN 00029092. doi: 10.2307/1242634. URL http://www.jstor.org/stable/1242634 http://about.jstor.org/terms http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=9604290257&site=ehost-live.

Trisha Shrum, William Travis, Travis Williams, and Evan Lih. Managing Climate Risks on the Ranch with Limited Drought Information. *Climate Risk Management*, 2018.

A. J. Smart, J. D. Derner, J. R. Hendrickson, R. L. Gillen, B. H. Dunn, E. M. Mousel, P. S. Johnson, R. N. Gates, K. K. Sedivec, K. R. Harmoney, J. D. Volesky, and K. C. Olson. Effects of Grazing Pressure on Efficiency of Grazing on North American Great Plains Rangelands. *Rangeland Ecology and Management*, 63(4):397–406, 2010. ISSN 15507424. doi: 10.2111/REM-D-09-00046.1. URL http://dx.doi.org/10.2111/REM-D-09-00046.1.

Harvey Sprock, Ben Berlinger, and Daniel Nosal. Reference Sheet for Ecological Site: Loamy Plains R067BY002CO. *United States Department of Agriculture Natural Resources Conservation Service*, 2004. URL https://esis.sc.egov.usda.gov/ESDReport/fsReport.aspx?approved=yes&rptLevel=all&id=R067BY00

N R St-Pierre, B Cobanov, and G Schnitkey. Economic losses from heat stress by US livestock industries. *Journal of Dairy Science*, 86(31):E52–E77, 2003. ISSN 00220302. doi: 10.3168/jds.S0022-0302(03)74040-5. URL http://dx.doi.org/10.3168/jds.S0022-0302(03)74040-5.

P. K. Thornton, J. van de Steeg, A. Notenbaert, and M. Herrero. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems*, 101(3):113–127, 2009. ISSN 0308521X. doi: 10.1016/j.agsy.2009.05.002. URL `http://dx.doi.org/10.1016/j.agsy.2009.05.002`.

United States Department of Agriculture. Cattle Death Loss. *National Agricultural Statistics Service*, page 5 pp., 2011.

US. Department of Labor. Farmers, Ranchers, and Other Agricultural Managers, 2017. URL `www.bls.gov/ooh/management/farmers-ranchers-and-other-agricultural-managers.htm#tab-3`.

USDA. MLRA Definitions. *Natural Resources Conservation Service*, 2005. URL `https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053625`.

USDA. Farms and Land in Farms: Numbers, Acreage, Ownership, and Use. Technical Report September 2014, 2014. URL `www.agcensus.gov`.

USDA. USDA Rainfall Index 2015, 2015a. URL `webapp.rma.usda.gov/apps/ActuarialInformationBrowser2015/RICriteria.aspx`.

USDA. Risk Management Agency Summary of Business Reports and Data, 2016. URL `http://www.rma.usda.gov/data/sob.html`.

Risk Management Agency USDA. Pasture, Rangeland, Forage Pilot Insurance Program, 2015b.

USDA Economic Research Service. Annual cash receipts by commodity, 2017. URL `https://data.ers.usda.gov/reports.aspx?ID=17832`.

USDA Risk Management Agency. Pasture, Rangeland, Forage Pilot Insurance Program, 2015. URL `https://www.rma.usda.gov/pubs/rme/prfinsprog.pdf`.

USDA-RMA. Rainfall and Vegetation Index Insurance Standards Handbook. Technical report, 2017. URL `rma.usda.gov/handbooks/18000/2018/18_18150.pdf`.

L W Vantassell, R K Heitschmidt, and J R Conner. Modeling Variation in Range Calf Growth under Conditions of Environmental Uncertainty. *Journal Of Range Management*, 40(4): 310–314, 1987.

Theopolis Waters. U.S. Drought In 2013 Hurts Cattle Ranchers With Dry, Poor Wheat Crop, mar 2013. URL `https://www.huffingtonpost.com/2013/01/14/us-drought-2013-cattle-ranchers_n_2469742.html`.

World Bank. World Agricultural financing. pages 32–80, 2012.

Yuanhe Yang, Jingyun Fang, Wenhong Ma, and Wei Wang. Relationship between variability in aboveground net primary production and precipitation in global grasslands. *Geophysical Research Letters*, 35(23):2–5, 2008. ISSN 00948276. doi: 10.1029/2008GL035408.

Appendix

	Insurance	No Ins	All
Number of Participants	254	286	540
Age			
Average Age	35.2	34.2	34.7
Gender			
Female	112	94	206
Male	172	158	330
Other	1	1	2
NA	4	2	6
Race			
White or Caucasian	204	234	438
Black or African American	20	21	41
Asian	16	12	28
American Indian or Alaskan Native	2	1	3
Other	11	15	26
NA	4	4	8
Income			
Less than $15,000	15	26	41
$15,000 to $29,999	59	53	112
$30,000 to $44,999	46	58	104
$45,000 to $59,999	44	44	88
$60,000 to $74,999	44	40	84
$75,000 to $89,999	16	19	35
$90,000 to $104,999	12	14	26
$105,000 to $149,999	18	28	46
NA	3	5	8

Figure 5: Demographic characteristics of the MTurk study population.

	Insurance	No Ins	All
Education			
Less than high school	1	0	1
High school diploma or equivalent	93	90	183
Trade school degree or certificate	12	9	21
Associate degree	38	52	90
Bachelors degree	98	109	207
Graduate degree (Masters, PhD, MD, JD)	11	23	34
NA	4	4	8
Vote			
I nearly always vote for Democrats	82	84	166
I vote for Democrats more often than	51	71	122
I vote for Republicans	29	16	45
Half the time I vote for Democrats and half the time I vote for Republicans	33	37	70
I vote for Republicans more often than I vote for Democrats	19	22	41
I nearly always vote for Republicans	18	17	35
I am not eligible to vote	4	1	5
I am eligible, but I never vote	16	36	52
NA	5	3	8
Prior Ranching Knowledge			
Nothing	202	227	429
I've read or talked about cattle ranching at least once before	43	49	92
I am familiar with cattle ranching	8	8	16
I work on or run a cattle ranch (or did so in the past)	1	0	1
NA	4	2	6
Environmental Leanings			
Identifies as an Environmentalist	87	106	193
Identifies as a vegetarian or vegan	17	15	32
Drought Knowledge and Impact			
Average Personal Impact of Drought from 1 to 7 scale (1 = No Impact)	2.429134	2.323944	7
I've read or talked about drought at least once before	108	132	240
Nothing	78	82	160
I am familiar with drought	63	66	129
I am very knowledgeable about drought	5	5	10
N/A	3	2	5

Figure 6: Demographic characteristics of the MTurk study population, continued.

Table 6: Sensitivity of Model to Outliers

	Dependent variable:			
	Herd Size			
	All	Exclude Large	Exclude Zeros	Exlcude Zeros and Large
	(1)	(2)	(3)	(4)
Insurance	0.0002	−0.005	0.004	0.001
	(0.017)	(0.011)	(0.010)	(0.006)
Risk Aversion	0.020**	0.010*	0.014***	0.008**
	(0.008)	(0.006)	(0.005)	(0.003)
Herd_{t-1}	0.001***	0.002***	0.001***	0.002***
	(0.00001)	(0.00002)	(0.00001)	(0.00002)
Herd_{t-2}	0.0003***	0.001***	0.0001***	0.001***
	(0.00001)	(0.00002)	(0.00001)	(0.00002)
Constant	5.657***	4.752***	5.812***	5.047***
	(0.013)	(0.012)	(0.009)	(0.011)
Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	4,950	4,870	4,670	4,590
Log Likelihood	−79,047.960	−64,848.100	−60,798.920	−51,075.850
Akaike Inf. Crit.	158,125.900	129,726.200	121,627.800	102,181.700
Bayesian Inf. Crit.	158,223.500	129,823.600	121,724.600	102,278.200

Note: *p<0.1; **p<0.05; ***p<0.01

GLMM model with a Poisson distribution and individual random effects.