THE VALUE OF CLIMATE FORECAST INFORMATION IN THE RANGE CATTLE STOCKING DECISION

by

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DEDICATION

In loving memory of Jack Adams and Mary Lou Sohm.

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ABSTRACT

Since precipitation is a crucial component for forage production in the southeastern rangelands of Arizona, ranching operations in this region are highly vulnerable to fluctuations in climate patterns. If crude ENSO forecasts are the only type of climate information available to a rancher, can this information improve resource management strategies and influence the stocking decision? The stocking decision is modeled for the San Carlos cow-calf ranching operation through a stylized dynamic stochastic framework utilizing El Niño Southern Oscillation (ENSO) forecasts that represent qualitatively different types of climate activity such as El Niño and La Niña events to determine the value of climate forecast information in the range cattle stocking decision. ENSO forecasts can lead to improved ranch profits as well as lower average stocking rates.

CHAPTER 1: INTRODUCTION

1.1 Arizona Drought

Drought has been a crippling economic factor throughout Arizona for several years. During May of 2002, the state of Arizona was officially declared a drought disaster area. Phoenix reported 2002 to be the driest year on record since 1952, when only 2.82 inches of rain fell. Enduring drought conditions have imposed numerous costs upon several stakeholder groups within the state's economy.

Cattle ranchers represent a segment of Arizona stakeholders that have been directly affected by current drought conditions. Drought conditions and above normal temperatures caused 85% of Arizona rangelands to be classified as "poor" or "very poor" at some point during the summer of 2002. Arizona officials have estimated the loss to the livestock industry for 2002 to be upwards of $300 million dollars.

1.2 Climate Variability

Although there is no commonly accepted definition of drought based on a measurable process, a drought is generally referred to as a period of time with low precipitation levels. Ranchers grazing livestock in the southeastern rangelands of Arizona, particularly on the Apache Indian Reservation in San Carlos, Arizona, depend upon summer monsoons and winter precipitation to provide adequate forage for their range cattle (See Figure 1.1). El Niño Southern Oscillation (ENSO) forecasts can provide ranchers with important information to utilize when implementing stocking rates.

ENSO forecasts predict the occurrence of El Niño and La Niña events for a given year. These forecasts provide information regarding winter precipitation. Winter precipitation for a given year represents accumulated precipitation from October of one year through March of the following year. For example, the winter precipitation for 2004 would be representative of the accumulated precipitation for October of 2003 through March of 2004.

El Niño events occur when ocean temperatures in the Equatorial Pacific are warmer than usual, while La Niña or El Viejo events occur when ocean temperatures in the Equatorial Pacific are cooler than usual. During an El Niño event, the stronger jet stream directs storms from the northwest to the south. This climate phenomenon brings wetter than average conditions to the southwest, although there have been several normal and dry El Niño years. During La Niña years, the jet stream is weakened, bringing drier than normal conditions to the southwest.

The Southern Oscillation Index (SOI) provides a measure for the strength of an El Niño or La Niña event. The southwestern signal that identifies El Niño and La Niña events is much stronger in the southwest offering ranchers in the southwest an opportunity to take advantage of ENSO events more than ranching operations located in other regions of the United States. The use of ENSO forecasts in making stocking rate decisions can improve production efficiency.

Climate scientists do not have the ability to accurately forecast next year's precipitation based on the current year's precipitation levels, but have been able to increase the accuracy of forecasting and identifying different ENSO states. ENSO states represent qualitatively different types of climate activity such as El Niño and La Niña events. If ENSO forecasts are the only type of climate information available to a rancher, can this information improve resource management strategies? This is the pertinent question that this paper will explore by studying the San Carlos cow-calf ranching operation and applying average observed characteristics to a dynamic stochastic framework to investigate stocking rates, profit implications, and the value of climate forecast information to the range cattle stocking decision.

1.3 Forage Production

Forage is the rangeland herbage available to grazing animals. Forage is accessible to range cattle by means of grazing or as mechanically harvested feed. Forage is the primary input for range cattle production within the San Carlos cow-calf ranching operation. Cattle grazing on the San Carlos Apache Indian Reservation depend upon forage as their primary source of sustenance. In the absence of supplemental feed, weight gains occur from forage consumption. Precipitation is the major force in shaping climate patterns that encourage plant and forage production. Water deficiency, especially during drought periods, lead to a reduction in plant growth patterns (NDSU Dickinson Research Extension Center).

Precipitation also plays a major role in the reproductive level of range cattle because cows will not cycle or come in "heat" without sufficient body condition and health. The amount of forage accessible to livestock directly affects the overall condition and productivity of the animal. With little rain, existing range conditions deteriorate, leading to malnourished cattle that may have difficulty reproducing and milking for calves. Another effect of not having adequate forage available to meet the consumption demands of grazing livestock is reduced weaning weights in calves. This situation results in lower rents captured by the rancher because of marginal weight decreases in the calf crop.

1.4 Cow-Calf Ranching Operation

The majority of the ranching operations in Arizona are cow-calf operations (Arizona Agricultural Statistics). Cow-calf enterprises are relatively widespread throughout the United States. The 1997 Census of Agriculture stated that there were approximately one million farms that had cow and calf inventories that generated $40.5 billion is sales. These inventories accounted for 21 percent of total market value for agricultural products and ranked first in sales among all commodities in the United States.

The San Carlos cow-calf operation is comprised of a maintained heifer population which is bred annually by a much smaller stock of bulls. The calf crop produced by the breeding process is the primary income source for a cow-calf ranching operation. The majority of the calf crops, except for heifer replacements, are sold after the first year to feedlots and other institutions. The R-100 herd of the San Carlos Apache Indian Tribe at Arsenic Tubs, Arizona, consists of commercial Hereford cattle. Hereford cattle represent a special class of domesticates that were originally bred in Hereford, England. Their ability to adapt to various range conditions has distinguished them as a highly versatile animal.

The primary goal of the rancher overseeing a cow-calf operation is to maximize profits generated through calf and cull cow sales. In order to minimize costs, there are several issues that need to be properly assessed. Ensuring a profitable cow-calf ranching operation requires minimizing calf mortality and keeping open cow levels relatively low to maximize the calf crop. Adequate supplies of forage are necessary for the health and reproductive capabilities of the herd. The ability to efficiently utilize the natural range resource can drastically increase calf production in terms of animal units by encouraging a healthier herd. Income is seasonal for a cow-calf ranching operation and is directly impacted by the availability of forage and prevailing climate conditions.

1.5 Research Motivation

The presence of drought in Arizona has had a significant impact on ranching operations throughout the state. Examining the implications that drought and ENSO forecasts have on ranching profitability in terms of animal unit production via forage production from rainfall can be explored through the application of natural resource economics to the real world scenario of the San Carlos cow-calf ranching operation.

1.6 Research Objectives

The primary objective of this paper is to develop a stylized economic model that incorporates both economic theory and climate forecast information in the stocking decision and determines the value of climate forecast information for this stocking decision process. Applying the theory of natural resource economics to the San Carlos cow-calf ranching operation in a stylized dynamic stochastic framework can illustrate how climate variability affects range cattle stocking decisions and profitability.

In this stylized model, ranchers, cattle, and precipitation determine the size of the natural renewable resource stock, which in this case will be the aggregated weight of the herd in animal units per year given varying ENSO states. ENSO forecasts that identify different climate events can be utilized to determine the value of climate forecast information in the stocking decision.

Forage production, range conditions, along with overall animal health and performance are major factors considered by ranchers when determining stocking rates. With a greater understanding of how climate variability affects the growth pattern of range cattle, ranch managers can make more informed decisions concerning stocking rates to promote more efficient production processes and improve ranch profitability. Other objectives include investigating ranch viability and the natural resource implications of different types of climate forecast information.

1.7 Data

The data utilized in this analysis comes from the Registered Hereford herd of the San Carlos Apache. The sample consists of 1,584 observations of calves born during the years 1980 through 1986, as well as 1988 and 1989, for a sample representing nine years of data. The data from 1987 were unobserved due to personnel at the University of Arizona on leave.

Each observation in the data corresponds to a particular calf which is identified by a five digit identification number. The first two digits of each identification number represents the year in which each calf was born. Along with the individual identification numbers, the observed data includes gender, birth weight, birth date, a three month weight and weighing date, an eighth-month weight and weighing date, a twelve-month weight and weighing date, and a twenty-month weight and weighing date.

The climate data utilized in this analysis represents region specific precipitation data collected from the Western Regional Climate Center (WRCC) website. This data was used to calculate cool season precipitation levels and serve as a control variable for climate conditions found in the San Carlos region between the years 1979 and 1990. Cool season precipitation represents the accumulated rainfall that fell between the months of November and April, measured in inches. Cool season precipitation values were calculated for the San Carlos region and used in regression analysis, discussed later in section 6.4, to account for the contribution that cool season precipitation has on observed birth weights and weight gains of calves.

Other climate data utilized in this analysis are Arizona winter precipitation data and El Niño Southern Oscillation (ENSO) data for Arizona obtained from the Western Regional Climate Center (WRCC) website and the Institute for the Study of Planet Earth (ISPE). The Arizona statewide winter precipitation data is historical precipitation data that represents the total amount of rainfall, measured in inches, which fell between the months of October and March for the years 1896 through 2001. The El Niño Southern Oscillation (ENSO) data classifies the years 1896 through 2001 into El Niño, La Niña, or Neither events based upon the year's average Southern Oscillation Index (SOI) value. These data are used in the value of climate forecast information simulation, described in section 6.6, to evaluate the profit implications of having different levels climate forecast information. An exhaustive description of the data and data processing methods can be found in APPENDIX A: Data Descriptions and Processing Methods.

CHAPTER 2: LITERATURE REVIEW

2.1 Renewable Resource Economics

The literature focusing on natural resource economics is a vast collection that explores the interactions between the environment and the complex economic system prominent in today's society. Natural resources exist in our natural environment and provide numerous factors of production. Economics is a tool used to understand and dissect these issues systematically and interactively between interconnected issues. For the San Carlos cow-calf ranching operation, there is direct link between the natural resources provided by the environment and the saleable beef that can be produced from the range resource.

Most of the literature concerning natural renewable resources focuses on common property or open access resources with little discussion of privately owned renewable resources. Chappel and Dowd (1999) state that, "the economics of privately owned renewable resources has received considerably less attention, and existing models of the economics of privately owned resources tend to be relatively incomplete." One of the contributions of this thesis is to further explore the issues involved with managing a privately owned natural renewable resource through a dynamic investment problem that focuses on a privately owned renewable resource.

Cattle represent a privately owned renewable resource managed by a rancher who has complete control of stocking rates. Cattle populations are confined by boundaries as opposed to the open access or common property scenario. These boundaries include but are not limited to fenced-in pastures and or land leasing agreements. Within a cow-calf operation, the rancher has exclusive, transferable, and enforceable property rights of the herd.

2.2 Harvesting and Stocking

In order for natural resources to be utilized in production processes they must be extracted or harvested. Harvesting renewable resources requires decision making over time. Without the implementation of appropriate harvesting and stocking rates, renewable resource stocks can either become significantly reduced or reach a point where population levels exceed the environments natural carrying capacity. Both circumstances result in inefficient exploitation of the resource. The derivation of harvesting rates can be found in much of the renewable resource literature focusing on topics such as mining, timber harvesting, and fishery management. The harvesting decision is a vital component to consider when managing renewable resources. Harvest rates are directly linked to stocking rates. Holecheck et. al (1998) states that, "stocking is the most important part of successful range management."

2.3 Climate Variability and Range Cattle Production

The relationship between harvesting rates, stocking rates, rangeland management, and ranching profitability is further complicated by climate variability. The uncertainty present in the stocking rate decision stems from the lack of information relating to long-term future climate forecasts. With significant advances in the ability of climatologists to forecast different ENSO states, ranchers can utilize this information to modify current management strategies.

The adoption of climate forecasts has been compared to the adoption of a new technology into the production process. Hill et al. (1998) conclude that, "the use of ENSO-based forecasts may improve efficiency of input usage, a characteristic of technological advances." Another contribution of this paper is to analyze the impacts of ENSO forecasts in determining stocking rates and assess the value of this information and the role it plays in promoting ranch profitability. The introduction of climate information, focusing on ENSO forecasts, to the range cattle production process provides a unique method to analyze stocking decisions and ranch profitability.

2.4 Summary

The economic activities of harvesting and stocking derived in the natural resource economics literature can be applied to the San Carlos cow-calf ranching operation to serve as a real world representation of how climate variability impacts beef production and the profitability of a cow-calf operation. Incorporating ENSO forecasts into a dynamic stochastic framework, determining the value of ENSO forecast information in the stocking rate decision process, and analyzing how these interactions impact ranch profitability are the primary focuses of this paper. Implementing appropriate stocking rates is essential to the profitability of a ranching operation in areas where climate dictates range conditions. In an efficiently managed ranching operation, range cattle can exist as a sustainable renewable resource that provides a stream of benefits to ranch resources and management.

CHAPTER 3: RESOURCE MANAGEMENT

3.1 Introduction

Users of natural resources must make decisions over time. In the cow-calf operation of the San Carlos Apache, resource management decisions are driven by increasing costs of harvesting and are further complicated by a variety of variables. These variables include but are not limited to rates of harvest, stocking rates and restrictions, growth rates, market prices, discount rates, range conditions, climate conditions, and costs associated with the production process. Careful analysis of how each of these variables impact the production process is vital when managing a profitable cow-calf ranching operation.

Proper management of a ranching operation requires that much attention be directed towards range condition. Among many other important biological and environmental concerns, improper grazing can lead to a situation where cattle fully exhaust the available forage of an area. It is essential for the rangeland manager to decide upon appropriate stocking rates that promote herd productivity, ranch profitability, and environmental quality while considering the implications of future precipitation events.

3.2 Range Utilization

Grazing systems utilized throughout Arizona by rangeland managers are quite diverse due to varying climate conditions. A grazing system is a schedule or plan used to designate the times and locations where livestock should graze. The main goal of developing a grazing system is to ensure that the range has sufficient periods of rest to promote full recovery of forage species. Implementing a grazing system is especially important during periods of drought when forage production is precarious. The key aspect of range management is proper stocking rates.

Healthy cattle are directly linked to the availability of adequate forage. Drought significantly reduces forage reproduction and requires the implementation of management strategies that incorporate proper stocking rates and grazing systems. In order for forage to be efficiently harvested and ensure future productivity of rangelands, grazing livestock should be managed in a manner that encourages rotational grazing. Rotational grazing gives the grazed range time to replenish its soil with forage. In the presence of drought, it is essential to pay close attention to range conditions to ensure an adequate forage supply for the grazing herd. Inadequate forage supplies translate to marginal weight losses within the herd and ultimately foregone profits.

The rangeland manager must understand and support the grazing system. Systems should be adjusted to meet changing climate conditions. Rotation periods and stocking rates must meet the needs of forage reproduction to ensure future productivity of rangelands. Grazing systems that meet the growth requirements of range plants ensure soil conservation and thus promote productive ranges, increased marginal weight gains, and ranch profitability.

3.3 Stocking Restrictions

Stocking rates are the number of specified kinds and classes and animals utilizing a unit of land for a specific time period (Frost and Ruyle, 1993). Stocking rates are almost always expressed in animal unit months (AUM's) or animal unit years (AUY's). The notion of a stocking restriction can be described as a constraint placed on the rancher by regulation or other means that limits the total number of head allowed to graze on a particular range. The introduction of stocking restrictions constrains the rangeland manager to stock the range at a particular level. Restrictions may result in drastic changes to the current management strategy implemented.

The Bureau of Land Management (BLM) and Forest Service have been granted the exclusive authority to control livestock grazing on public lands. Both institutions have the power to regulate stocking rates and management practices should they judge a given portion of rangelands to be degraded. For the San Carlos Apache, grazing permits and allotments are regulated by the Tribal Council.

In prospering times, when forage is thriving and precipitation levels are at least average, stocking restrictions can potentially have a significant impact on the profitability of a cow-calf operation holding all other economic factors constant. The possibility of capturing additional rents from an increase in animal unit production with higher stocking rates is lost. In addition, stocking restrictions that are set too high in this scenario may result in overgrazing and competing demands for food and ultimately lost profits due to the marginal weight gain in the cattle biomass.

On the other hand, stocking restrictions may promote profitability by forcing a ranching operation to stock at rates that meet the carrying capacity of the range, encouraging efficient exploitation of the range resources, and ultimately promoting efficient range cattle production. This outcome may prove to be more suitable in times of drought when range resources are highly vulnerable to climate fluctuations. The argument to this approach is that inappropriate stocking restrictions may be placed on a range that does in fact have the potential to be stocked at a higher rate.

The stocking restrictions of the San Carlos cow-calf ranching operation appear to be more relaxed than those of the typical ranching operation. Rangeland managers operating within the San Carlos Apache Reservation are able to implement stocking rates that they feel are optimal as long as the Tribal Council agrees. Thus, rangeland managers are able to set stocking rates without running into an externally enforced limit. This provides the ideal laboratory to study the interaction between stocking and precipitation.

3.4 Economic Problem

The preceding discussion highlights the major points of the economic problem that this paper aims to address: The management of renewable resources under uncertainty with resource and profit implications. This economic problem can be systematically analyzed by adapting the average observed characteristics of the San Carlos cow-calf operation to the natural resource theory of harvesting and applying a dynamic stochastic framework.

CHAPTER 4: METHODOLOGY

4.1 Theoretical Framework

The theoretical framework utilized in this analysis stems from the models used throughout the natural resource economics literature focusing on the harvesting decision. Adapting the theory of the harvesting decision into a two-period dynamic stochastic framework and applying the average observed characteristics of the San Carlos cow-calf ranching operation along with climate forecast information provides a unique way to analyze the management strategies of a privately owned renewable resource.

A herd of cattle can be thought of as a stock or biomass of cattle belonging to a particular rancher whose primary goal is to maximize profits. In the case of the San Carlos cow-calf ranching operation, the rancher is the sole owner of the cattle who has exclusive property rights to the exploitation of the resource stock. The stock or biomass of the herd is the aggregate weight of all the cattle and can be measured in animal units (au). An animal unit is equal to one mature (1,000 lb.) cow or the equivalent based upon an average daily forage allowance of 26 lbs. of dry matter per day under range conditions (Frost and Ruyle, 1993). Ranchers, cattle, and precipitation jointly determine the size of the renewable resource stock over time.

Within the cattle biomass or stock, there are a number of different cattle with varying biological traits such as sex, age, and weight. Flows result from changes in the stock over an interval of time. These changes result from biological factors and economic factors alike. In the ranching scenario, flows relate to harvesting rates, fertility rates, and mortality rates. The crucial biological variables that influence the cattle biomass are its size, growth rate, individual growth of members in the stock, and mortality. The economic factors that affect the biomass are the harvesting decisions made by the rangeland manager. These decisions are based upon the costs and revenues associated with the harvesting process along with expectations of future climate patterns.

The three components that determine the growth rate of the biomass are recruitment, individual growth, and natural mortality. The growth rate of the stock is dependent upon reproduction. Growth rates can be evaluated through herd fertility rates. Recruitment occurs when new calves are born into the herd or replacement cattle are brought into the herd to replace culled or perished cattle. Individual growth occurs when individual cattle within the population increase in weight, increasing the aggregate weight or biomass of the herd population. Weight gains of the cattle biomass in terms of animal units are directly linked to the availability of forage which is directly linked to climate conditions. Exogenous factors such as climate variability can be a more important determinant of the total population at each point in time than the biomass itself. Natural mortality occurs when there is a decrease in the herd biomass from natural death or predation that may occur in a given time period. Recruitment and individual growth contribute to the overall stock size while mortality diminishes it. Due to biological and physical changes in a renewable resource, the supply curve of the biomass is constantly shifting.

The range upon which cattle graze may be limited to the total number of head that it can support at a given time. The maximum population level that a given habitat or ecosystem can support on a sustainable basis is known as carrying capacity. In livestock production, forage is the key ingredient that determines the carrying capacity of rangelands, while prevailing climate conditions determine the amount of forage available to livestock. The lack of adequate precipitation contributes to the range's inability to produce forage and ultimately diminishes the range's ability to promote growth within the cattle biomass because range cattle depend upon forage as their primary source of sustenance in the absence of supplemental feed.

Little or no precipitation can lead to poor range conditions where there is not enough forage to support the biomass present on the range. This situation would lead to competing food requirements and ultimately a declining biomass growth rate. If the cattle stock were to exist with no outside influences, persisting stock levels would be in a natural or bionomic equilibrium. This bionomic equilibrium exists when recruitment and individual growth are equal to natural mortality.

The static steady state efficient sustainable yield is the sustained harvest level that produces the largest annual recurring net benefit. A sustainable yield is achieved by setting the annual harvest equal to the annual net growth rate of the population. This condition represents harvest levels that can be maintained indefinitely. The maximum sustainable yield is the maximum harvest that could be sustained forever.

It is important to distinguish between open access and private property scenarios when deriving equilibriums for the theoretical harvesting decision model. For the San Carlos cow-calf operation, the rancher is the sole owner of the resource stock and has complete control over the exploitation of the privately owned renewable resource stock.

This condition holds with the absence of outside regulation enforcing stocking restrictions.

The open-access equilibrium and the private property equilibrium in a static model can be derived in terms of effort or in terms of harvests. The open-access equilibrium condition in terms of effort exists where total revenue of effort equals the total cost of effort and in terms of harvests where price equals the average cost of the harvest. The equilibrium condition for the private property scenario, in terms of effort, exists where the marginal revenue equals the marginal cost of effort, or in terms of harvests, where price equals the marginal cost of the harvest. The equilibrium condition of a private property scenario reflects that of a monopolistic firm. In the San Carlos cow-calf operation, the rancher has complete control over all stocking decisions.

The private property equilibrium is efficient compared to the inefficient open-access equilibrium that prevails because the marginal revenue of effort is less than the marginal cost of effort and the price is less than the average cost of harvest. Open-access effort levels always exceed the effort levels of private property scenarios due to the presence of competition. Open-access harvests can be greater, equal to, or less than the private property harvests.

The static economic rents captured under a private property scenario are maximized compared to the zero rents captured in the open-access scenario. The private property scenario results in biological efficiency because effort does not exceed the maximum sustainable yield harvest. It is possible to obtain biological efficiency in the open-access scenario if effort is to the left of the maximum sustainable yield harvest. Efficiency is associated with maximizing the net benefits from the use of the resource.

In order to successfully adapt the theoretical framework of the harvesting decision to the San Carlos cow-calf ranching scenario, there are some relevant issues that must be addressed. The justification and motivation behind using a dynamic two-period model and the assumptions made to validate the modification of the theoretical model utilized in this analysis are engaged in the following sections.

4.2 Dynamic Approach

Static efficiency is the chief normative economic criterion for choosing among various allocations when time is not an important consideration. Dynamic efficiency is the chief economic criterion for choosing among various allocations occurring at different points in time. An allocation satisfies the dynamic efficiency criterion if it maximizes the net present value of net benefits that could be received from all possible ways of allocating resources over time. The dynamic efficient sustainable yield is the sustained yield that produces the highest present value of net benefits while incorporating a positive discount rate.

The inclusion of a discount rate is what distinguishes the dynamic steady state equilibrium from the static steady state equilibrium. Incorporating a discount rate is necessary to quantify the impacts that stocking rates, growth rates, and climate variability have on ranching profitability through time and ultimately ranch viability. In the case of the San Carlos cow-calf ranching operation, dynamic effects must be considered to ensure long term profits due to growth fluctuations that occur in the cattle biomass from varying climate conditions over time.

The justification for the use of a dynamic modeling approach rather than a single period static model stems from the profit implications that climate variability has on determining optimal stocking rates. In the steady state model, there is no discount rate applied to the costs and revenues associated with future harvests. The absence of a discount translates to the rancher being indifferent to earning a dollar today versus earning a dollar tomorrow.

In the presence of a private property equilibrium where dynamic effects are considered, the discount rate usually lies between zero and infinity. With a positive discount rate the static and dynamic private property equilibriums do not coincide and the sole owner of the resource stock is faced with the fact that harvests tomorrow are worth less than profits today. While some argue that the appropriate social discount rate is zero, many economists believe that a preference for profits received today rather than tomorrow should be accounted for when calculating a socially optimal policy.

To reach a dynamic equilibrium, a harvest rate must be chosen such that the net return to investing is equal to the discount rate. In the cow-calf operation, the return on investment into the cattle biomass must be equal to the discount rate to promote ranch viability. If net returns are not equal to the discount rate, it does not make sense to continue to invest in the operation. Net return to investing includes the sum of capital gain from holding stock from one period to the next, stock externality, and biological growth from one period to the next.

The two-period model presented in this paper will incorporate the theoretical framework of the harvesting decision into a profit maximizing function. Climate variability will be introduced into this two-period model under a stochastic framework which uses single period-prediction distributions from ENSO forecasts with a positive discount rate.

4.3 Model Assumptions

The dynamic stochastic two-period model presented in this paper is simplified in a natural way to incorporate the variables driving the rangeland manager's decision process and the implications these variables have on renewable resource management and ranching profitability. The observed characteristics of the San Carlos cow-calf ranching operation are incorporated into the model by transforming data into forms that replicate a natural renewable resource management scenario. Many of these adaptation methods have already been defined in the theoretical framework described in section 4.1.

The derivation of the theoretical harvesting model is built upon some underlying assumptions that can be stylized to represent the characteristics of the cow-calf operation. First, the price of harvest is assumed constant and does not depend on the amount sold. This assumption applies to the cow-calf operation in that a market price exists for calves and cows at the time of sell. The second assumption states that the marginal cost of a unit of effort is held constant. This assumption is appropriate in that the marginal cost of harvesting one animal unit is the same as the marginal cost of harvesting another animal unit from the same cattle biomass.

In addition to the underlying assumptions already embedded in the theoretical model, there are some additional assumptions that must be addressed to validate the modeling process. It is necessary to assume that the rancher's main objective is to maximize the net present value of net benefits being derived from the exploitation of the cattle biomass while ignoring fixed costs such as maintenance costs and ENSO forecasts are the information and variability influencing the rancher's decision process when considering stocking rates.

It is important to clarify that the model derived here assumes two discrete time periods and that the cow-calf operation starts with an initial biomass of cattle in the first period. The stock of the second period is directly linked to the animal units harvested or stocked in the first period. The rancher must decide how much of the biomass to harvest until the cost of harvesting outweighs the benefits derived from harvesting.

It is assumed that the rancher must commit and stay with a stocking rate before the actual precipitation occurs. The rancher would ultimately like to be operating at an optimal stocking rate in the first period to take full advantage of the available range resources and produce the greatest amount of saleable beef possible with the existing range conditions. The cost associated with not operating at the optimal stocking rate in the first period is equal to the foregone profits of the additional biomass that could have been obtained from operating at the optimal stocking level.

CHAPTER 5: MODEL APPLICATION

5.1 Dynamic Two-period Model Derivation

In order to determine the stocking rate that maximizes the stream of net benefits captured from exploitation of the cattle biomass, a dynamic two-period profit maximizing function is derived. Next, climate variability is introduced into the dynamic model in a stochastic framework and the resulting model can then be manipulated to produce an optimal stocking rate that maximizes the rents derived from renewable resource utilization. Further analysis of the dynamic stochastic two-period model derived here demonstrates how stocking rates impact the profitability of a cow-calf ranching operation when climate uncertainty is introduced.

In a cow-calf ranching scenario, total profits are equal to the sum of the animal units produced in the first production period plus the discounted value of the animal units produced in the subsequent period minus the animal units harvested in each period. For tractability and clarity, the marginal costs associated with stocking are ignored. This dynamic two-period profit relationship can be represented by,

$$(1)\ \pi = \pi_1 + \frac{\pi_2}{1+\Delta},$$

where π is the sum of profits derived from each discrete period, π_1 represents the profits for the first period, and π_2 represents the profits for the second period discounted at a positive discount rate, Δ.

Due to the direct link between the harvest rate and the biomass stock, the biomass stock of each discrete period can be defined as the difference between the recruitment or growth of the biomass and the harvest of that period. These relationships can be represented by,

(2) $S_1 = R_1 - Y_1$, and

(3) $S_2 = R_2 - Y_2$,

where S_1 and S_2 represent the biomass stock of each discrete period measured in animal units, R_1 and R_2 represent the biomass recruitment or overall herd growth in terms of animal units during each discrete period, and Y_1 and Y_2 represent the harvest of each discrete period.

Since the profits in a cow-calf ranching operation are derived from the total animal units of calves produced and sold in each production period, the second period harvest is defined as the recruitment or growth of the initial cattle biomass because the rancher sells all calves at the beginning of the second production period except those kept for heifer replacement. This relationship can be represented as,

(4) $Y_2 = R_1 = G(S_1)$,

where Y_2 represents the second period harvest, R_1 represents the biomass recruitment or overall herd growth of the first period in terms of animal units for the first period, and $G(S_1)$ represents the logistic based growth function of the initial cattle biomass in terms of animal units. The assumed logistic based growth function is described in greater detail in section 5.4 and APPENDIX B: The Logistic Based Growth Function.

The relationship in equation (4) illustrates the reproductive characteristics of the San Carlos herd as well as the production and climate period synchronization. Recruitment into the cattle biomass during the first production period results from calves being born into the herd as well as the weight gains of existing calves. The majority of the calves produced in the San Carlos herd are born in the early spring and do not begin grazing until later that year or at the beginning of the second production period.

For the first several months of a calf's life, the primary source of sustenance comes from the mother's milk. The mother's milk comes from nutrients provided by forage, so calf performance is always somewhat impacted by the quality of available forage produced by winter precipitation of the previous year. It is not until after the weaning process that calves rely completely on forage produced from winter precipitation of the current year as their primary source of sustenance.

Using the relationships described in equations (2), (3), and (4), the dynamic two-period model can be rewritten and simplified as,

$$(5)\ Max\pi = (P-C)(R_1 - S_1) + \frac{(P-C)(G(S_1) - S_2)}{1+\Delta},$$

where π is the total profits derived from both discrete periods, P and C represent the output price and cost of harvesting, R_1 represents recruitment or the additional animal units introduced into the biomass during the first period, S_1 represents the initial biomass stock of the first period measured in animal units, $G(S_1)$ represents the growth of the initial biomass stock measured in animal units, S_2 represents the biomass stock of the second period measured in animal units, and Δ represents a positive discount rate.

5.2 The Dynamic Stochastic Two-period Model

Since precipitation promotes forage production and forage is the only source of sustenance for cattle grazing on the San Carlos rangelands, the marginal growth of the cattle biomass is directly associated with prevailing climate conditions. The growth of the cattle biomass must be weighted to account for the additional growth that precipitation contributes to the cattle biomass.

In order to introduce climate variability into the dynamic two-period model, αZ is introduced into the dynamic two-period profit function to account for the impact that precipitation has on recruits. Z represents actual or expected precipitation and is assumed to be a random variable independently and identically distributed, and α is rainfall scaling factor.

Introducing climate variability, in terms of αZ, into the dynamic two-period model in equation (5) produces the two-period model as,

$$(6)\ Max\pi = (P - C)(R_1 - S_1) + \frac{(P - C)(\alpha Z G(S_1) - S_2)}{1 + \Delta},$$

where π is the total profits derived from each discrete period, P and C represent the output price and cost of harvesting, R_1 represents recruitment or the additional animal units introduced into the biomass during the first period, S_1 represents the initial biomass stock of the first period measured in animal units, $\alpha Z G(S_1)$ represents the biomass growth based on stocks and precipitation measured in animal units, S_2 represents the cattle biomass of the second period measured in animal units, and Δ represents a positive discount rate.

Due to the presence of uncertainty associated with climate variability, the rancher's primary goal is to maximize expected profits. So, the expected profits for the dynamic stochastic two-period model in equation (6) can be represented by,

$$(7)\ Max\pi = (P-C)(R_1 - S_1) + \frac{(P-C)(\alpha E(Z)G(S_1) - S_2)}{1+\Delta},$$

where $\alpha E(Z)G(S_1)$ represents the scaled weighted growth that expected precipitation contributes to the initial cattle biomass measured in animal units.

It is important to notice that a marginal increase in the cattle biomass increases the number of recruits measured in animal units at a decreasing rate as the stocking level increases, based on the amount of available forage. It is assumed that forage availability depends entirely on the current year precipitation. This trend continues until the supply of forage is eventually exhausted.

5.3 The Golden Rule of Investment

From the dynamic stochastic two-period model in equation (6), it is possible to derive the critical elements necessary for this analysis and address the economic problem that this paper aims to explore: (1) How uncertainty of climate variability influences the stocking decision, and (2) how this decision impacts the profitability of a cow-calf ranching operation. The resource extraction problem that emerges determines the optimal number of animal units to stock in the first production period given the expected climate conditions to take full advantage of available range resources and maximize the stream of benefits captured from resource exploitation. The stocking rate for the second period is determined by boundary conditions to be discussed later.

Taking the partial derivative of the dynamic stochastic two-period model in equation (6) with respect to S_1 produces,

$$(8)\ \frac{\partial \pi}{\partial S_1} = (P - C)(-1) + \frac{1}{1+\Delta}(P - C)\alpha Z \frac{dG(S_1)}{dS_1}.$$

Setting the partial derivative in equation (12) equal to zero yields,

$$(9)\ (P - C)(-1) + \frac{1}{1+\Delta}(P - C)\alpha Z G'(S_1) = 0.$$

Solving the necessary condition in equation (9) for $\alpha Z G'(S_1)$ produces the following result,

$$(10)\ \alpha Z G'(S_1) = 1 + \Delta,$$

where αZ accounts for the additional growth that precipitation contributes to the cattle biomass in terms of animal units, $G'(S_1)$ is the first derivative of the biomass growth function as a function of the initial cattle biomass measured in animal units, and Δ represents a positive discount rate.

The key element driving the two-period model is the financial principal known as the golden rule of investment. The basic premise behind the golden rule of investment is to balance the net returns of an investment against the discount rate. It only makes sense to undertake an investment as long as there is a net return on the initial investment that is at least equivalent to the initial investment. Equation (10) represents a stylized version of the golden rule of investment for capital accumulation. The modification applied to the golden rule of investment is the inclusion of αZ. The modified version of the golden rule of investment for capital accumulation can be used to determine whether or not investing into the ranching operation in terms of animal units is as valuable as investing into a different venture other than ranching when climate variability is introduced.

The modified golden rule of investment in equation (10) is an important concept that illustrates the marginal animal unit choice that the rancher is faced with: As stocking levels increase, the marginal animal unit increase from recruitment becomes less and less and the rancher must decide how to balance this effect against the discount rate or cost of borrowing. The rancher would ultimately like to maximize expected profits by taking full advantage of the available range resources and produce enough additional biomass to balance the discount rate. If the condition in equation (10) is not satisfied, it would make more sense for the rancher to seek an alternative investment venture such as depositing money into a savings account and accruing interest on the principal amount.

5.4 The Logistic Growth Function and Optimal and Targeted Stocking Rate

It is now possible to derive the optimal stocking rate from the dynamic stochastic two-period model utilizing the logistic based growth function (Conrad and Clark, 1987) that accounts for the biological mechanisms of the cattle biomass. The assumed logistic based growth function of the cattle biomass can be expressed as,

$$(11)\quad G(S_1) = S_1 + rS_1\left(1 - \frac{S_1}{k}\right) = S_1 + rS_1 - \left(\frac{rS_1^2}{k}\right),$$

where $G(S_1)$ represents the growth of the cattle biomass measured in animal units, S_1 represents the initial cattle biomass measured in animal units, r represents the biomass intrinsic growth rate that quantifies how much a population can grow between successive time periods, and k represents the carrying capacity of the range in terms of animal units.

The first derivative of the logistic based growth function in equation (11) is,

$$(12)\ G'(S_1) = 1 + r - \frac{2r}{k} = 1 + r\left(1 - \frac{2S_1}{k}\right).$$

Substituting equation (11) into the modified golden rule of investment in equation (9) produces,

$$(13)\ \alpha Z\left(1 + r\left(1 - \frac{2S_1}{k}\right)\right) = 1 + \Delta .$$

Rearranging the terms in equation (13) produces,

$$(14)\ S_1 = \left(\frac{k}{2r\alpha Z}\right)(\alpha Z(1 + r) - (1 + \Delta)).$$

Since the result in equation (10) was derived from a necessary condition for a maximum, solving for S_1 yields the optimal stocking rate for the first discrete time period in the dynamic stochastic two-period model in equation (6). The optimal biomass stocking rate for the dynamic stochastic two-period model can be represented by,

$$(15)\ S_1^* = \left(\frac{k}{2r\alpha Z}\right)(\alpha Z(1 + r) - (1 + \Delta)),$$

where S_1^* represents the optimal stocking rate for the base period in the dynamic stochastic two-period model in terms of animal units, k represents the carrying capacity of the range in terms of animal units, r represents the biomass intrinsic growth rate that quantifies how much a population can grow between successive time periods, αZ adjusts the optimal stocking rate for precipitation, and Δ represents a positive discount rate.

For further derivations, the logistic based growth function in equation (11) will be denoted by the following relationship,

$$(16)\ R^* = S_1^* + rS_1^*\left(1 - \frac{S_1^*}{k}\right),$$

where R^* represents the actual weighted growth of the cattle biomass in terms of animal units, S_1^* represents the optimal cattle biomass for the base period measured in animal units, r represents the biomass intrinsic growth rate that quantifies how much a population can grow between successive time periods, and k represents the carrying capacity of the range which the cattle graze upon in terms of animal units.

Using the relationships derived in equations (15) and (16), the optimal stocking rate and the growth of the cattle biomass can be substituted into the dynamic stochastic two-period model in equation (6) to create the dynamic stochastic two-period model as,

$$(17)\ Max\pi = (P - C)(R_1 - S_1^*) + \frac{(P - C)(R^* - S_2)}{1 + \Delta},$$

where π is the total profits derived from both discrete periods, P and C represent the output price and cost of harvesting, R_1 represents recruitment or the additional animal units introduced into the biomass during the first period, S_1^* represents the optimal stocking rate or choice variable facing the rancher for the first production period measured in animal units, R^* represents the actual weighted growth of the initial cattle biomass measured in animal units, S_2 represents the targeted stocking rate for the second production period measured in animal units, and Δ represents a positive discount rate.

5.5 The Infinite Time Horizon Solution

For a logistic growth function and independently and identically distributed disturbances, a steady state optimal stocking rate exists. With no information regarding climate events of the second production period, the stochastic infinite time horizon problem simplifies to yield a constant Most Rapid Approach Path (MRAP) optimal stocking rate, S_{∞}^{*}, based on average precipitation (Conrad and Clark, 1987. As in the two-period problem, S_{∞}^{*}, is also governed by the golden rule of investment.

The stochastic two-period stocking problem and the stochastic infinite horizon are linked because it is assumed that ENSO forecast information provides improved precipitation information for the coming year. No information is available (other than the historical average) for the precipitation beyond the coming season. Thus, a rancher making stocking decisions for a given year faces the infinite horizon problem delayed one year into the future.

For the stocking decision governing the current year the rancher faces the two-period problem, which incorporates the additional information of the ENSO forecast. In addition, the most rapid approach nature of the stocking problem means that the rancher will attempt to adjust to S_{∞}^{*} as soon as it is relevant.

The rancher's optimization problem is thus to apply the two-period problem for the coming season, with a target stocking rate where S^* equals S_∞^* for the second season, and arriving at a stocking rate for the coming season that takes advantage of the additional ENSO forecast information. Once the second production period arrives, new ENSO forecast information is available. Because the rancher can adjust stocking rates to take advantage of the new ENSO forecast information, the rancher again deviates from S_∞^* to utilize the forecast information on the coming season. Therefore the solution to the stochastic infinite horizon stocking problem is to repeatedly apply the two-period problem each year utilizing the newly revealed ENSO forecast information. For more information regarding the infinite time horizon solution see Conrad and Clark, 1987.

CHAPTER 6: EMPERICAL RESULTS

6.1 Calibration Process

In order to successfully apply the dynamic stochastic two-period model, function parameters must be calibrated to represent average observed characteristics of the San Carlos cow-calf ranching operation. The first step in the calibration process requires establishing a fertility and mortality rate for the cattle biomass.

The second step in the calibration process is to establish a stylized animal unit definition for the San Carlos cow-calf ranching operation. This stylized animal unit definition can then be used to convert function parameters into similar animal unit measures to have consistency across function parameters.

For the next step in the calibration process, regression analysis is implemented to estimate birth weights and first year weight gains of the 1,584 calves present in the San Carlos data set as a function of gender and cool season precipitation. The parameter estimates for the two models are then converted using the stylized animal unit definition, adjusted for gender, and incorporated with average fertility and mortality rates to establish the average observed growth present in the average San Carlos herd. Finally, unknown parameters present in the optimal stocking function and the logistic growth function can be solved for to complete the calibration process and successfully apply the dynamic stochastic two-period model.

6.2 Fertility and Mortality Rates

Average fertility and mortality rates utilized in this analysis are derived from the data summarized in the articles, "Value of Pregnancy Testing," and "Range Cow Culling: Herd Performance," written by Tronstad et. al. Average fertility and mortality rates are needed to represent the average biological and reproductive activity of the San Carlos herd and establish the average actual growth, R^*, of the cattle biomass. The main advantage of using the data summarized in the article is that it is representative of the San Carlos cow-calf ranching operation.

In order to accomplish the task of determining an average fertility rate to represent the San Carlos biomass, the pregnant fertility rates for cows with sale calf at side, the fertility rates for pregnant cows with no calf at side, and the pregnant to live newborn calf calving rates for pregnant cows by age are paired by age. Then, the fertility rates for pregnant cows with sale calf at side are multiplied by the pregnant to live newborn calf calving rates for pregnant cows by age and summed with the product of the fertility rates for pregnant cows with no calf at side and the pregnant to live newborn calving rates for pregnant cows by age. The products are then divided in half and multiplied by the percentage of the herd by age and summed across all ages to produce an average fertility rate to represent the San Carlos biomass. The calculated average live calf fertility rate for the San Carlos cow-calf ranching operation can be represented by,

(18) $f = 0.7639 = 76.39\%$,

where f represents the average weighted live calf fertility rate of the San Carlos herd.

In order to calculate an average mortality rate to represent the San Carlos herd, the newborn calf at side to cow died estimates fertility rates of open cows with calf by age are added to the open to cow dies estimated fertility rate of open cows with no calf by age, divided in half, and multiplied by the percentage of herd by age. The products are then summed across all ages to produce an average mortality rate to represent the San Carlos biomass. The average mortality rate for the San Carlos herd can be represented by,

(19) $M = 0.0380 = 3.80\%$,

where M represents the average mortality rate for the San Carlos herd that accounts for reproduction loss. M accounts for culled cows and calves since culled livestock still have an implied value.

The average mortality rate for the San Carlos herd can be redefined as,

(20) $L = 1 - M = 1 - 0.0380 = 0.9620 = 96.20\%$,

where L represents the probability of survival for cattle in the San Carlos herd.

6.3 The Stylized Animal Unit Definition

The animal unit definition derived for this analysis is derived to convert function parameters into an animal unit measure and create a stylized animal unit measure that resembles the average characteristics of the San Carlos cattle stock. Animal unit equivalents from the USDA National Range and Pasture Handbook were used to establish a stylized animal unit definition for this analysis.

The animal unit equivalence for a 1,000 lb. cow with calf as defined in the USDA National Range and Pasture Handbook is equal to 1.00 animal unit and a 1,000 lb. cow with no calf is defined as 0.92 animal units. So, one animal unit is equal to one 1,000 lb. cow plus calf. If a cow with no calf is equal to 0.92 animal units, then a calf is equivalent to 0.08 animal units. This implies that 1.00 animal unit is equivalent to 1,000 lbs. divided by 0.92 animal units. The resulting stylized animal unit measure can be defined as,

(21) 1.00 AU = 1,087 lbs. or 1,087 lbs. per AU.

The average birth weight for the calves observed in the sample is 84.14 pounds. Thus, the stylized animal unit definition in equation (21) is consistent with the average calf weight of calves in the San Carlos herd with minor variation.

6.4 Estimation and Parameter Conversion

Ordinary least squares is utilized to the estimate birth weights and yearling weight gains of the 1,584 calves in the sample. The birth weight and first year weight gain of each individual calf is estimated as a function of gender and region specific cool season precipitation. The region specific cool season precipitation serves as a control variable to represent the San Carlos climate conditions. Typically, biomass growth occurs due to cool season precipitation. The parameter estimates produced from the ordinary least squares estimation process are converted in terms of the stylized animal unit definition derived in equation (21) and used in the calculation of R^*.

Since a calf is only observed once for its birth weight and or first year weight gain, the analysis are not time series, but instead two separate ordinary least squared regressions. For the first several months of a calf's life, the primary source of sustenance comes from the mother's milk. The mother's milk comes from nutrients provided by forage, so calf birth weights are always somewhat impacted by the quality of available forage produced by cool season precipitation of the previous year. The calf birth weight model is represented by,

(22) $BW_t = \beta_0 + \beta_1 SEX + \beta_2 CSP_{t-1}$,

where BW represents the estimated calf birth weight in pounds, SEX is an indicator variable that accounts for gender ($SEX = 1$ if female and $SEX = 0$ if male), and CSP represents the region specific cool season precipitation of the previous year for San Carlos, Arizona measured in inches.

It is not until after the weaning process that calves rely completely on forage produced from cool season precipitation of the current year as their primary source of sustenance. The yearling weight gain model is represented by,

(23) $WG_t = \gamma_0 + \gamma_1 SEX + \gamma_2 CSP_t$,

where WG represents the estimated twelve month weight gain of calves measured in pounds, SEX is an indicator variable that accounts for gender ($SEX = 1$ if female and $SEX = 0$ if male), and CSP represents the region specific cool season precipitation of the current year for San Carlos, Arizona measured in inches. The estimation results and model specifications for the models described in equations (22) and (23) are summarized in TABLE 6.1 and TABLE 6.2.

It is now possible to convert the parameter estimates of the calf birth weight model in equation (22) and the parameter estimates of the yearling weight gain model in equation (23) using the stylized animal unit definition in equation (21). The purpose of the parameter conversion process is to define the parameter estimates in terms of animal units to achieve a standard unit of measure to be used in the calculation of R^* being that the estimated calf birth weights and estimated yearling weight gains are measured in pounds.

The first step in the parameter estimate conversion process is dividing the SEX parameter estimate in half to account for the fact that of the 1,584 calf observations in the sample, 789 or 49.81 percent of the calf sample is male, while 795 or 50.19 percent of the sample is female. Adding the intercept to half of the SEX parameter estimate and dividing the sum by the stylized animal unit definition is equation (23) produces the following relationship,

$$(24)\ \beta_{AU_1} = \frac{\beta_0 + \frac{\beta_1}{2}}{1{,}087},$$

where β_{AU_1} is assumed to be a converted parameter estimate that accounts for birth weight differences due to gender in terms of animal units, β_0 represents the intercept for the calf birth weight model, and β_1 represents the SEX parameter estimate for the calf birth weight model.

The second step in the parameter estimate conversion process is to account for the weight that cool season precipitation contributes to calf birth weights in terms of animal units. As described earlier, cool season precipitation represents the accumulated rainfall that falls between the months of November and April and is measured in inches. This region specific precipitation data is used in regression analysis to replicate the climate conditions in San Carlos, Arizona for the observed years in the sample.

Dividing the parameter estimate for CSP by the stylized animal unit definition in equation (21) and post multiplying by the average cool season precipitation produces the following relationship,

$$(25)\ \beta_{AU_2} = \frac{\beta_2}{1{,}087}\overline{Z},$$

where β_{AU_2} is assumed to be a converted parameter estimate that accounts for the weight that cool season contributes to calf birth weight in terms of animal units, β_2 represents the parameter estimate for CSP, and $\overline{Z}$ represents the average cool season precipitation value of 8.21 inches for the San Carlos region for the years observed in the calf data.

Utilizing the assumed relationships derived in equation (24) and equation (25), the calf birth weight model can be rewritten as,

$$(26)\ BW_{AU} = \beta_{AU_1} + \beta_{AU_2},$$

where BW_{AU} represents the birth weight of a calf accounting for gender differences and average cool season precipitation weight contributions in terms of animal units.

Applying the same conversion method done to the calf birth weight parameter estimates to the yearling weight gain model produces the following relationships,

$$(27)\ \gamma_{AU_1} = \frac{\gamma_0 + \frac{\gamma_1}{2}}{1{,}087}, \text{ and}$$

$$(28)\ \gamma_{AU_2} = \frac{\gamma_2}{1{,}087}\overline{Z},$$

where γ_{AU_1} is assumed to be a converted parameter estimate that accounts for yearling weight gain differences due to gender in terms of animal units, γ_0 represents the intercept for the yearling weight gain model, γ_1 represents the SEX parameter estimate for the yearling weight gain model, γ_{AU_2} is assumed to be a converted parameter estimate that accounts for the weight contribution that cool season provides in terms of animal units, γ_2 represents the parameter estimate for CSP, and $\overline{Z}$ represents the average cool season precipitation value of 8.21 inches for the San Carlos region for the years observed in the calf data.

Utilizing the assumed relationships derived in equation (27) and equation (28), the yearling weight gain model can be rewritten as,

(29) $WG_{AU} = \gamma_{AU_1} + \gamma_{AU_2}$,

where WG_{AU} represents the yearling weight gain of a calf accounting for gender differences and average cool season precipitation weight contributions in terms of animal units.

6.5 Actual Cattle Biomass Growth

The concepts derived in the preceding sections can now be applied in order to calculate the average actual growth of the San Carlos cattle biomass, R^*, in terms of animal units. To begin the derivation of R^*, assume that growth within the cattle biomass is equal to the sum of the average herd weight in terms of animal units excluding bulls, the new calves born into the herd in terms of animal units, and the growth of the yearling calves in terms of animal units minus perished livestock.

To determine the average herd weight in terms of animal units, the average number of cow calf pairs and the average number of open or cows without calves in the cattle biomass must be established. To accomplish this, assume that each calf is spawned from one cow creating one cow calf pair. According to the data, the average number of calves born into the San Carlos herd between the years 1980 and 1989, excluding 1987, was 287.78 per year. The average number of cows in the cattle biomass can then be determined by dividing the average number of calves by the average fertility rate in equation (18). This calculation yields 376.70 as the average number of cows.

The average number of open cows can then be calculated as the difference between the average number of cows and the average number of calves born into the herd. This calculation yields 88.92 as the average number of open cows present in the San Carlos herd. The animal unit equivalence for a 1,000 lb. cow with no calf as defined in the USDA National Range and Pasture Handbook is equal to 0.92 animal units, so the average number of open cows is equal to 81.81 animal units.

The average weight of the San Carlos biomass is equal to the sum of the average number of cow calf pairs in terms of animal units and the average number of open cows in terms of animal units. From the calculations above, the average cattle biomass or stock in terms of animal units can be represented by,

$$(30)\ \overline{H}_{AU} = 287.78 + 287.78\left(\frac{1}{f} - 1\right)0.92,$$

where $\overline{H}_{AU}$ represents the average cattle biomass in terms of animal units for the San Carlos herd, and f represents the average fertility rate for the San Carlos herd. The relationship in equation (30) can be simplified as,

$$(31)\ \overline{H}_{AU} = Calves\left(1 + 0.92\left(\frac{1}{f} - 1\right)\right),$$

where $\overline{H}_{AU}$ represents the average cattle biomass for the San Carlos herd in terms of animal units, $Calves$ represents the average number of calves born into the herd between 1980 and 1989, excluding 1987, and f represents the average fertility rate for the San Carlos herd. Calculating equation (31) yields 369.58 as the average cattle biomass weight for the San Carlos herd in terms of animal units.

From equation (26), the birth weight in terms of animal units of one calf is equal to, $BW_{AU} = \beta_{AU_1} + \beta_{AU_2}$, and from equation (29), the weight gain of one yearling calf is equal to, $WG_{AU} = \gamma_{AU_1} + \gamma_{AU_2}$. So, the birth weight of all new calves in terms of animal units can be represented by,

$$(32)\ BW_{AU_1} = (\beta_{AU_1} + \beta_{AU_2})\ \text{X}\ \textit{the average number of calves},$$

and the growth of all yearling calves can be represented by,

$$(33)\ WG_{AU_1} = (\gamma_{AU_1} + \gamma_{AU_2})\ \text{X}\ \textit{the average number of calves},$$

where BW_{AU_1} represents the birth weight of all new calves born into the San Carlos biomass in terms of animal units, and WG_{AU_1} represents the weight gains for all yearling calves in the San Carlos biomass in terms of animal units.

Utilizing the average probability of survival in equation (20) along with the relationships derived in equations (31), (32), and (33), R^* can be represented by,

(34) $R^* = \left(\overline{H}_{AU} + BW_{AU_1} + WG_{AU_1}\right)L$

where R^* represents the average actual growth of the San Carlos cattle biomass in terms of animal units, L represents the probability of survival for cattle in the San Carlos herd, $\overline{H}_{AU}$ represents the average cattle biomass for the San Carlos herd in terms of animal units, BW_{AU_1} represents the birth weight of all new calves born into the San Carlos biomass in terms of animal units, and WG_{AU_1} represents the weight gains for all yearling calves in the San Carlos biomass in terms of animal units. Calculating equation (34) yields the average actual growth of the San Carlos cattle biomass as 468.24 animal units. The average herd characteristics are summarized in TABLE 6.3.

6.6 Calibrated Parameters

In order to apply the stochastic dynamic two-period profit function in equation (17) and evaluate the profit implications of having different levels of climate forecast information, the parameters α, k, and r in equations (15) and (16) need to be solved for and calibrated to meet the characteristics of the San Carlos herd. According to the model, the average stocking rate is optimal for the average rainfall. Therefore, the modeled optimal stocking rate, S^*, is equal to the average stocking rate of the San Carlos cow-calf ranching operation, and the average recruits are assumed to be equal to $G\left(S^*, Z_{Average}\right)$. The three parameters are therefore calibrated by setting S^* equal to the average stocking rate for the San Carlos cow-calf ranching operation, setting $G(S^*)$ equal to the average number of recruits on the San Carlos rangelands, and by assuming the normalization that $\alpha\overline{Z} = 1$. As described earlier, k represents the carrying capacity of the range in terms of animal units, r represents the intrinsic growth rate of the cattle biomass, α is a factor that scales for precipitation, and Δ represents a positive discount rate.

To begin the parameter calibration, Z is replaced with $\overline{Z}$ in αZ to represent the average cool season precipitation value of 8.21 inches for the San Carlos region for the years observed in the calf data. The expected value of αZ is assumed to be equal to one for model calibration and $\alpha\overline{Z}$ is normalized to equal one. Thus, the calibrated α for the San Carlos region can be represented by,

$$(35)\ \alpha = \frac{1}{\overline{Z}} = \frac{1}{8.21} = 0.1219.$$

The next step in the calibration process is solving for the range carrying capacity, k. To accomplish this, the normalized relationship of $\alpha\overline{Z} = 1$ is substituted into the optimal stocking function in equation (15) and then k is solved for. The calibrated carrying capacity in terms of animal units can be represented by,

$$(36)\ k = \frac{2rS_1^*}{r - \Delta}.$$

The final step in the calibration process is to solve for intrinsic growth rate of the cattle biomass, r. This is accomplished by substituting the relationship derived in equation (36) into the logistic growth function that represents the actual weighted growth of the cattle biomass in equation (16) and solving the for r. The calibrated intrinsic growth rate of the cattle biomass can be represented by,

(37) $r = \frac{2R^*}{S^*} - 2 - \Delta$.

S^* and $\overline{H}_{AU}$ derived in equations (32) and (33) are quantitatively similar with minor rounding error, so the relationships in equations (36) and (37) can be rewritten as,

(38) $k = \frac{2r\overline{H}_{AU}}{r - \Delta}$, and

(39) $r = \frac{2R^*}{\overline{H}_{AU}} - 2 - \Delta$.

The positive discount rate, Δ, is a given constant that is defined as being equal to two percent for model calibration purposes due to the status of the San Carlos Apache reservation. If a numeric value for Δ is assumed, the calibrated carrying capacity for the San Carlos range and the calibrated intrinsic growth rate of the San Carlos cattle biomass can be calculated utilizing the derivation of $\overline{H}_{AU}$ in equation (31) and the derivation of R^* in equation (34). The calibrated carrying capacity of the San Carlos range, k, and the calibrated intrinsic growth rate of the San Carlos cattle biomass, r, evaluated at a two percent discount rate can be represented by,

(40) $k = 769.10$ animal units, and

(41) $r = 0.5139 = 51.39\%$.

The calibrated parameters for the dynamic stochastic two-period model based on two, five, and eight percent discount rates are summarized in TABLE 6.4.

6.7 Value of Climate Forecast Information

Traditionally, intuitive knowledge of how varying climate patterns impacted range resources drove the stocking rate decision. Today, advances in ENSO forecasting offer ranchers better information regarding future climate patterns than ever before. The problem complicating the ENSO forecast information is that not all forecasts prove to be accurate and are poor at predicting into the future. The presence of uncertainty in terms of climate variability can be a crippling factor for resource management and ranching profitability. Quantifying the profit implications associated with stocking and growth rates evaluated at different levels of climate forecast information can define the value of climate forecast information in the cattle production process.

To begin the value of climate forecast information analysis, the sample of 106 years of historical Arizona winter precipitation data for the time period 1896 to 2001 was categorized into ENSO events based upon the Southern Oscillation Index (SOI) value of each year (See Figure 6.1). El Niño years are represented by a SOI value less than -0.5, La Niña years are represented by a SOI value greater than 0.5, and Neither years are those years that have a SOI value between -0.5 and 0.5. El Niño years account for 31.13 percent of the sample, Neither years account for 46.23 percent of the sample, and La Niña years account for 22.64 percent of the sample. ENSO forecasts tell ranchers that the coming seasons winter precipitation will be a draw from the El Niño, Neither, or La Niña distributions. The historical Arizona winter precipitation distribution along with the winter precipitation distribution for each ENSO state can be seen in Figures 6.2, 6.3, 6.4, and 6.5.

As described earlier, ENSO forecasts predict the occurrence of El Niño and La Niña Events for a given year and provide information regarding winter precipitation. El Niño events occur with warmer ocean temperatures in the Equatorial Pacific encouraging a stronger jet stream that directs storms towards the southwest bringing wetter than average conditions to the southwest. La Niña events occur when cooler ocean temperatures in the Equatorial Pacific weaken the jet stream and bring drier than normal conditions to the southwest. According to Figure 6.1, La Niña events are almost always drier with an average winter precipitation value of 5.30 inches, while El Niño events have a higher than average winter precipitation value of 7.75 inches but is highly variable with both wet and dry years.

The purpose of dividing the historical Arizona winter precipitation data sample into the various ENSO states is to compare the implications that different levels of climate information have on the biomass growth in terms of animal unit production and how the stocking decision impacts the profitability of a cow-calf ranching operation. If ENSO state forecasts are the only type of climate information available to a rancher, can this information improve management strategies when the precipitation for a given year is an independent draw from the ENSO state of the given year and the separate distribution of each different ENSO state is known? In order to address this question, it is necessary to evaluate profit implications associated with different levels of climate forecast information.

The expectation of Z utilized in the optimization represents the different types of climate forecast information available to the rancher. In the baseline case, the rancher does not have ENSO forecast information and $\overline{Z}$ is the historical average winter precipitation. With perfect information, $\overline{Z}$ would be equal to the actual winter precipitation for a given year. The quality of $\overline{Z}$ completely represents the state of information of the rancher. With perfect ENSO forecasts, the individual ENSO state distributions can be utilized, instead of the entire historical winter precipitation data. If the rancher has ENSO forecasts, the rancher can set $\overline{Z}$ for El Niño years equal to the average winter precipitation for EL Niño years, the $\overline{Z}$ for La Niña years equal to the average winter precipitation during La Niña years, and the $\overline{Z}$ for years without El Niño or La Niña events equal to the average for these years.

In order to correctly evaluate the profit and stocking implications of having different levels of climate forecast information, the function parameters of the dynamic stochastic model must be adjusted. First, α must be adjusted to represent the average Arizona winter precipitation. From equation (35), $\overline{Z}$ is replaced with the average Arizona winter precipitation value of 6.21 inches. Thus, α can be represented by,

$$(42)\ \alpha = \frac{1}{\overline{Z}} = \frac{1}{6.21} = 0.1610\,.$$

To evaluate and compare profit and stocking implications associated with different levels of climate forecast information, the carrying capacity and the intrinsic growth rate are adjusted for a five percent and an eight percent discount rate. The five percent discount rate is chosen to represent a realistic discount rate, while a two percent discount rate and an eight percent discount rate are used to represent extreme cases. The range carrying capacity, k, and the calibrated intrinsic growth rate of the cattle biomass, r, adjusted for the different discount rates are summarized in TABLE 6.4.

The value of information can be quantified by evaluating an average optimal stocking rate using the expected value of precipitation levels and comparing them to an optimal stocking rate evaluated at actual precipitation levels. The stocking rates derived with actual precipitation levels provides some additional information that can be incorporated into the stocking decision, while stocking rates derived from expected precipitation levels represent a base line scenario.

The following function is utilized to evaluate the profit implications or changes in profits as the difference between having ENSO climate information and the knowledge of average rainfall from historical winter precipitation data. The difference between the different levels of climate forecast information represents the profit implications associated with imperfect information. The change in profits is evaluated as the difference between the rancher's profits when the rancher stocks according to an expected amount of winter precipitation but receives the actual amount of winter precipitation and if the rancher had stocked the amount appropriate for the actual amount of winter precipitation and received the actual amount of winter precipitation. The change in profits at different levels of climate forecast information for the stochastic dynamic two-period profit function is represented by,

$$(43)\quad \Delta\pi = \pi\left(S\left(\bar{Z}\right), Z_{Actual}\right) - \pi\left(S\left(Z_{Actual}\right), Z_{Actual}\right)$$

$$= S\left(\alpha Z_{Actual}\right) - S\left(\alpha \bar{Z}\right) + \frac{\left(\alpha Z_{Actual} G\left(S\left(\alpha \bar{Z}\right)\right) - \alpha Z_{Actual} G\left(S\left(\alpha Z_{Actual}\right)\right)\right)}{\left(1+\Delta\right)}.$$

Equation (43) can be simplified as,

$$(44)\ \Delta\pi = \frac{(1+\Delta)(Z_{Actual} - \overline{Z})^2}{(4rZ_{Actual}\overline{Z}^2\alpha)},$$

where $\Delta\pi$ represents the change in profits in terms of animal units, $\overline{Z}$ represents the expected value or average precipitation value of 6.21 inches based on the historical Arizona winter precipitation data, Z represents actual precipitation level for each year represented in the historical Arizona winter precipitation data, and Δ represents a positive discount rate.

Using the function in equation (44), along with the calibrated parameters for the different discount rates, the change in profits can be calculated by evaluating the fluctuations in animal unit production via stocking and growth rates evaluated at actual and expected values of precipitation based on historical winter precipitation and ENSO forecast data.

The intuition behind the relationship in equation (44), is to illustrate the premise of "losing less" with better information regarding future precipitation patterns, particularly with ENSO forecasts. Stated differently, the rancher is able to capture greater profits from marginal animal unit increases in the cattle biomass and manage resources more efficiently by implementing more efficient stocking rates with better averages calculated from ENSO forecasts. The ENSO forecast information provides a more accurate expected value of precipitation than that of the historical Arizona winter precipitation or none ENSO information. The rancher can optimize expected profits according to ENSO distributions which provide a more accurate measure of average rainfall to use in the stocking decision.

For the baseline case of no ENSO forecast, the simulation applies equation (43) to each year of historical Arizona winter precipitation data using the average historical winter precipitation as $\overline{Z}$, and the historical winter precipitation value for that year as Z_{Actual}. The average over all years provides the average loss to the rancher due to having only the average winter precipitation as opposed to perfect information. This process is repeated for the ENSO forecasts, with $\overline{Z}$ replaced with the average winter precipitation value for the appropriate ENSO state. This provides the losses that the rancher faces if they had perfect ENSO forecast information compared to perfect information forecasts. Because the rancher with ENSO forecasts has more information than the rancher with only the aggregated average, the rancher with ENSO forecasts faces less of a loss. The value of the ENSO forecast is therefore the decrease in average losses between the no forecast case and the ENSO forecast case. A detailed description of the simulation designed to quantify the value of climate forecast information can be found in APPENDIX C: The Value of Climate Forecast Information Simulation.

6.8 Stocking Rate Implications

TABLE 6.5 summarizes the stocking implications in terms of animal units associated with optimal stocking rates evaluated at a two, five, and eight percent discount rate for different levels of climate forecast information. From TABLE 6.5, we can see that on average, the range is being stocked correctly, but stocking levels are not properly adjusted for wet and dry years. EL Niño forecasts appear to be the most important form of climate forecast information available to a rancher since the range is under-stocked on average for each of the different discount rates, while La Niña years are overstocked on average for each of the different discount rates.

In El Niño years, the rancher is losing out on additional biomass or saleable beef that could be captured from stocking at a higher level. The rancher would want to implement higher stocking rates during El Niño years especially in the presence of a higher discount rate or cost of borrowing. Since on average, the range is being over stocked during La Niña years, ranchers would want to decrease stocking rates to a level that maximizes biomass growth given the inadequacy of the range and its diminished ability to produce forage for livestock consumption.

6.9 Profit Implications

TABLE 6.6 summarizes the profit implications associated with stocking rates evaluated at different levels of climate forecast information in the presence of a typical discount rate of five percent. The results represent losses, as described earlier in section 6.7, in terms of dollars per hundred weight and dollars per acre. The prices were chosen to represent dollar inputs. The $75.00 per hundred weight price is used to represent a typical net price while the other prices were chosen to see how price fluctuations influence profit losses.

When making a stocking decision, the rancher is aware of the total amount of acres available for livestock grazing.. There are approximately 100,000 acres of rangelands throughout the San Carlos reservation. This acre value is utilized in the loss per acre results.

The results in TABLE 6.6 show that on average, being able to identify ENSO states decreases profit losses, where El Niño forecast information has the greatest impact on profit loss reduction. The smaller the magnitude of the loss represents a gain in terms of losing less and the difference between the average loss and ENSO loss represents the value of the ENSO forecast information in the stocking decision. Stocking and profit implications are more pronounced in the presence of a higher discount rate.

CHAPTER 7: SUMMARY AND CONCLUSIONS

Stocking rates, biomass growth rates, and overall range and herd health are important aspects of a cow-calf ranching operation that can be significantly altered by fluctuations in climate conditions, directly impacting profits. Climate forecast information can be incorporated with stocking rate decisions to take full advantage of available forage and maximize the production of saleable beef. An increased quantity of forage produced and captured as a commodity can improve profit margins.

Implementing management strategies that promote efficient resource management and ranching profitability require reliable information of future climate events to be used in the range cattle stocking decision. Ranchers can utilize climate forecast information to adjust stocking rates to levels that promote biomass growth and ultimately the production of saleable beef. Reliable climate forecast information can help ranching operations reduce the uncertainty associated with climate variability in an industry that is typically not very profitable and directly impacted by climate variability.

Rangeland managers realizing the direct relationship between range cattle production and climate variability can develop more productive and efficient long-term management strategies. Rangeland managers can utilize climate forecast information when determining stocking restrictions for areas sensitive to climate fluctuations. Setting appropriate restrictions can help in preserving the natural state of rangelands while allowing ranchers to operate at efficient stocking levels.

With persistent drought conditions and the uncertainty of future precipitation patterns, climate variability is a critical issue that should be addressed to properly manage current herds and develop more efficient production strategies that promote the profitability and viability of ranching operations. Accurate climate forecasts can be a useful tool when implementing stocking rates. The results show ENSO forecasts to be a useful tool to be utilized in the stocking decision especially in the presence of a higher discount rate. ENSO forecasts can lead to improved ranch profits as well as lower average stocking rates and lower average stocking rates may contribute to environmental quality as well.

Figure 1.1 The San Carlos, Arizona Study Area

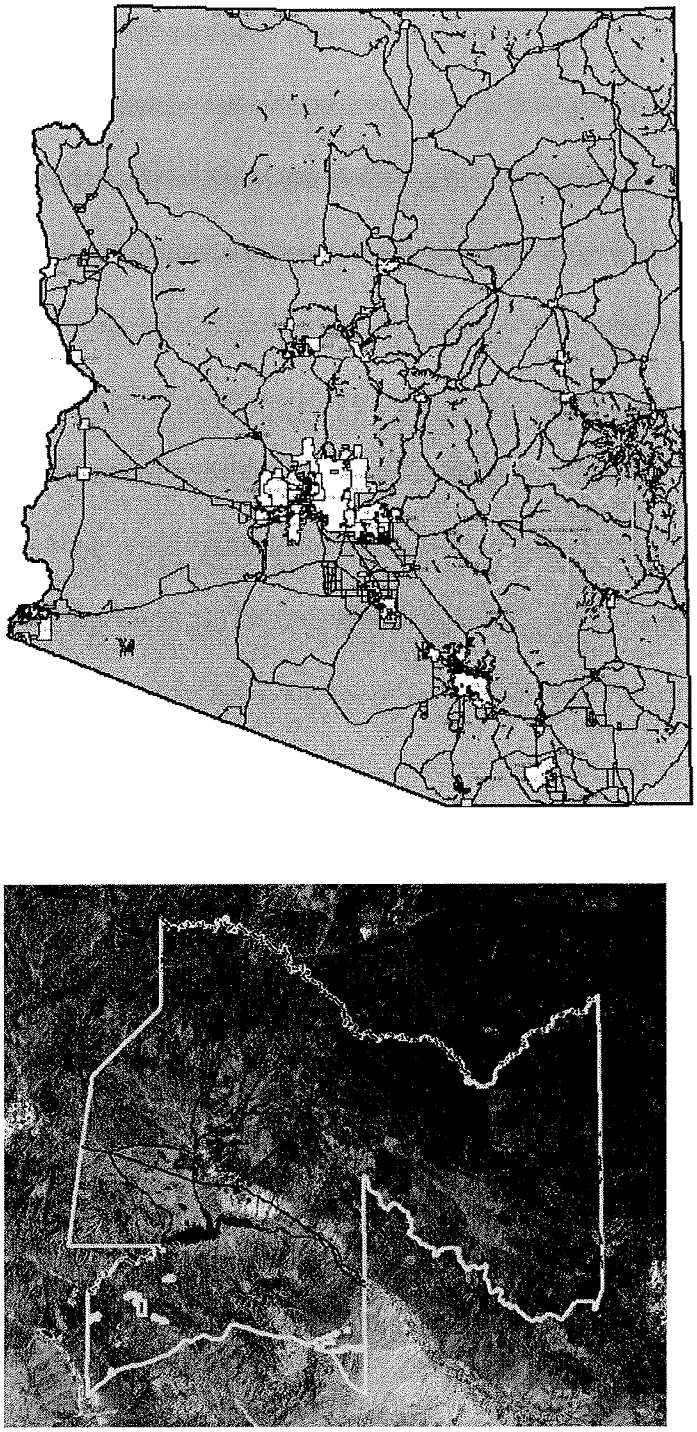

Figure 6.1 ENSO & Arizona Winter Precipitation (1896-2001)

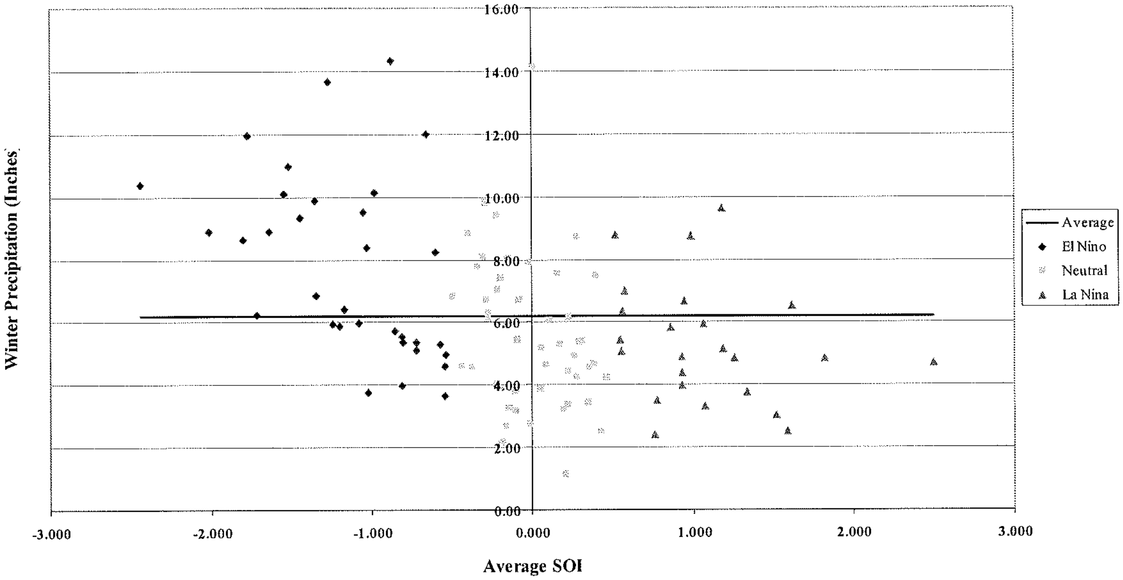

Figure 6.2 1891-2001 Arizona Winter Precipitation Distribution (106 Years)

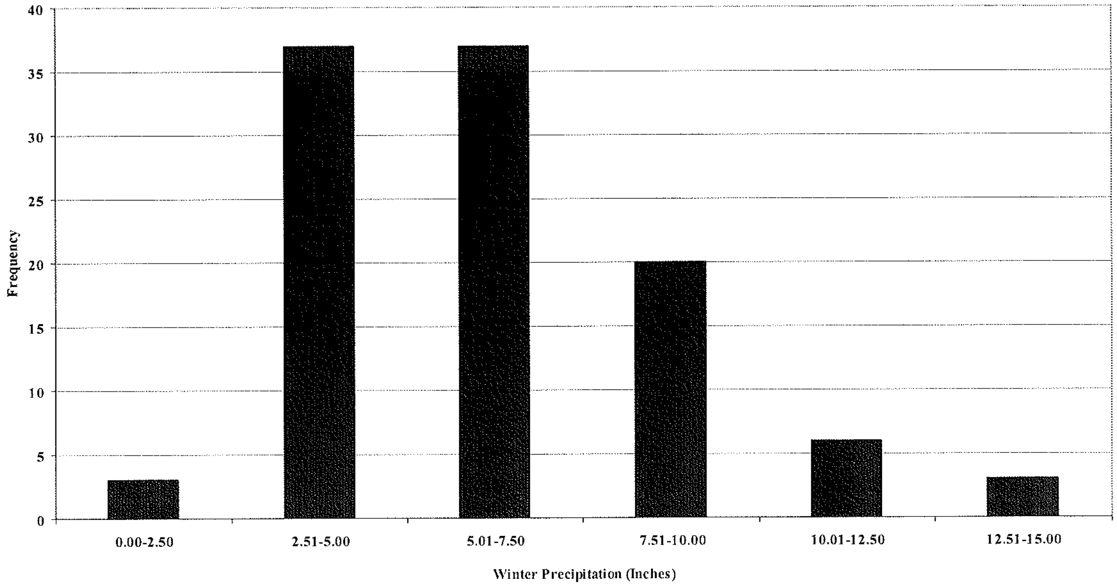

Figure 6.3 Arizona El Nino Winter Precipitation Distribution (33 of 106 Years)

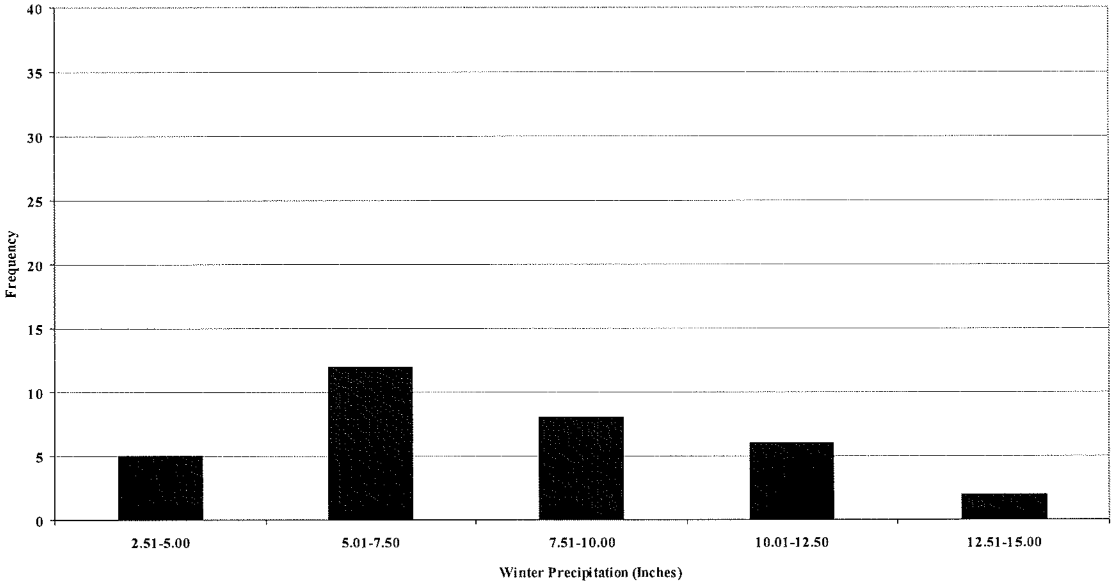

Figure 6.4 Arizona Neither Year Winter Precipitation Ditribution (49 of 106 Years)

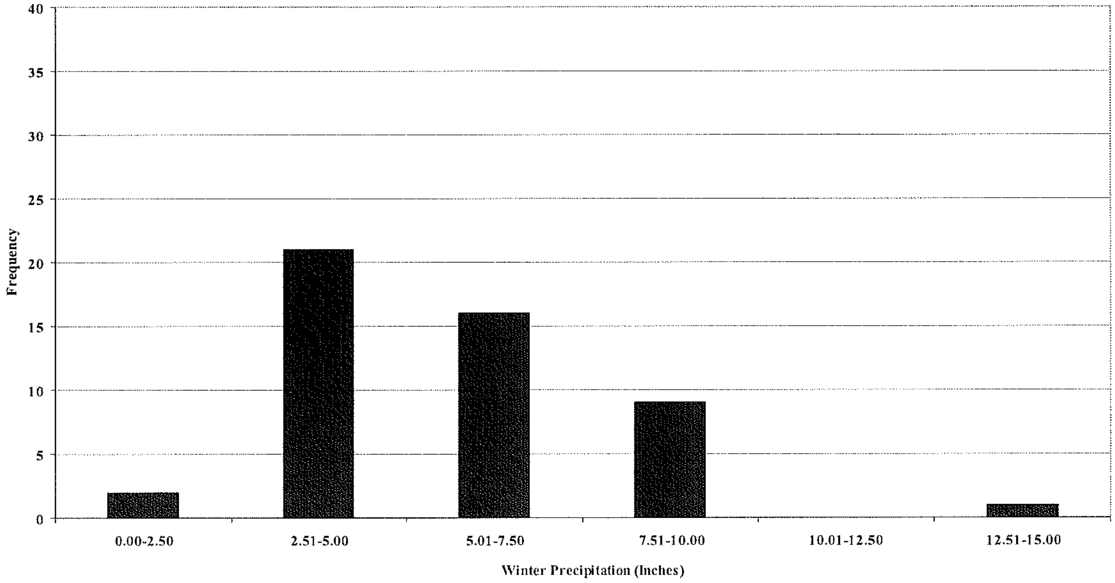

Figure 6.5 Arizona La Nina Winter Precipitation Distribution (24 of 106 Years)

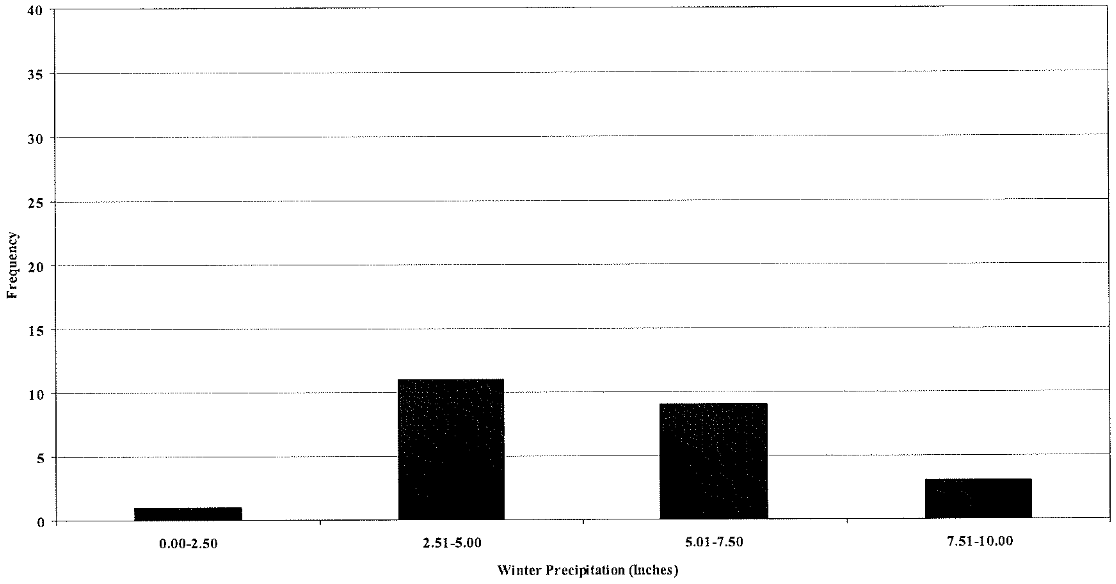

Figure 6.6 Decision Timeline

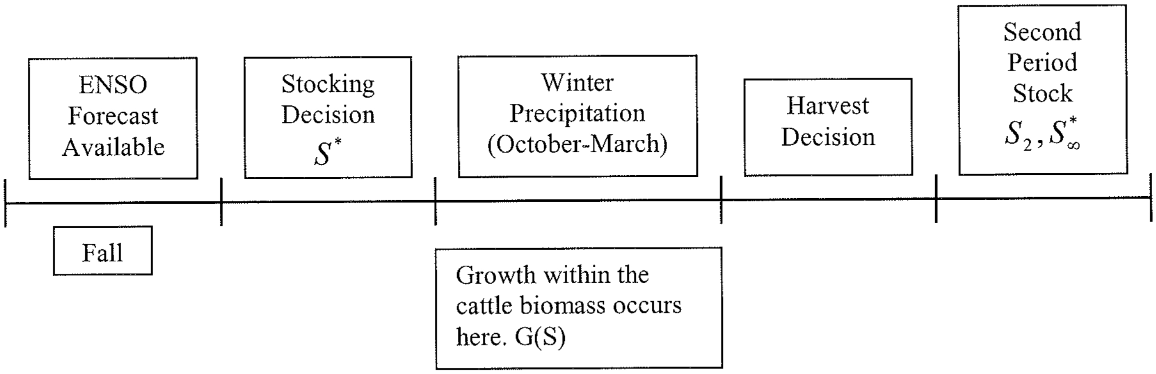

Figure 6.7 Regression Timelines

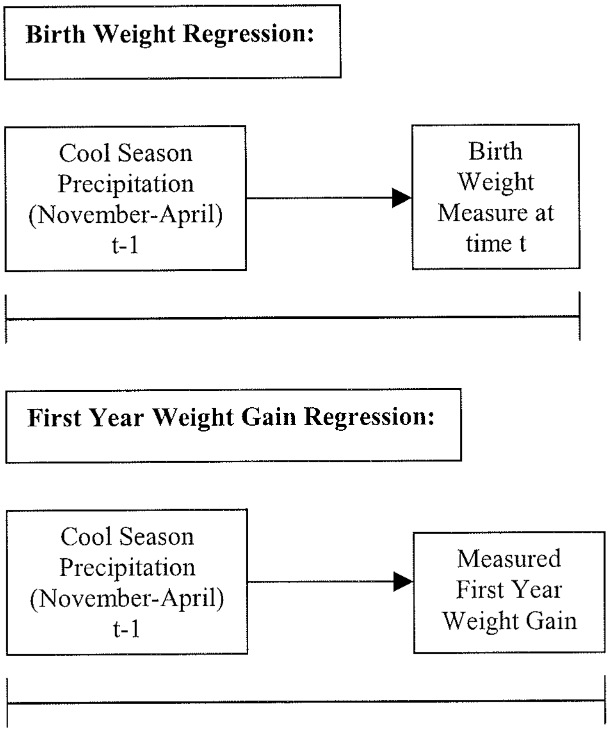

TABLE 6.1 Calf Birth Weight Estimation Results and Model Specifications

Variable	Estimate	Standard Error	t Value	Pr > |t|
Intercept	76.97513	0.90277	85.27	<.0001
SEX	1.71758	0.64477	2.66	0.0078
CSP	0.80411	0.10044	8.01	<.0001
Sample Size	1,584			
Root MSE	12.82671			
Dep Mean	84.13636			
Coeff Var	15.24514			
R-Square	0.0437			
Adj R-Square	0.0425			

TABLE 6.2 Yearling Weight Gain Estimation Results and Model Specifications

Variable	Estimate	Standard Error	t Value	Pr > |t|
Intercept	341.09381	5.94977	57.33	<.0001
SEX	10.25824	4.24953	2.41	0.0159
CSP	3.96167	0.66201	5.98	<.0001
Sample Size	1,584			
Root MSE	84.53845			
Dep Mean	377.2702			
Coeff Var	22.40793			
R-Square	0.0261			
Adj R-Square	0.0249			

TABLE 6.3 Average Herd Characteristics

Average Fertility Rate % (f)	76.39
Average Mortality Rate % (M)	3.80
Average Probability of Survival % (L)	96.20
Average Stocking Rate in AU's (S^*)	369.58
Average Actual Weighted Growth in Au's (R^*)	468.24

TABLE 6.4 Calibrated Parameters

	2% Discount Rate	5% Discount Rate	8% Discount Rate
Rainfall Scaling Factor (α)	0.1219	0.1610	0.1610
Carrying Capacity in AU's (k)	769.10	824.35	897.34
Intrinsic Growth Rate % (r)	51.39	48.39	45.39

TABLE 6.5 Stocking Rate Implications

		Average Rainfall in Inches	Average Stocking Rate in AU's	Average ENSO Stocking Rate in AU's	Difference
2% Discount Rate	None ENSO Winter Precipitation	6.21	370.12	370.12	0.00
	El Niño Winter Precipitation	7.75	370.12	521.53	-151.41
	Neither Winter Precipitation	5.58	370.12	283.28	86.84
	La Niña Winter Precipitation	5.30	370.12	238.80	131.31
	Average ENSO		370.12	347.38	22.74
5% Discount Rate	None ENSO Winter Precipitation	6.21	370.21	370.21	0.00
	El Niño Winter Precipitation	7.75	370.21	547.63	-177.42
	Neither Winter Precipitation	5.58	370.21	268.45	101.76
	La Niña Winter Precipitation	5.30	370.21	216.34	153.87
	Average ENSO		370.21	343.57	26.64
8% Discount Rate	None ENSO Winter Precipitation	6.21	370.33	370.33	0.00
	El Niño Winter Precipitation	7.75	370.33	582.11	-211.78
	Neither Winter Precipitation	5.58	370.33	248.87	121.46
	La Niña Winter Precipitation	5.30	370.33	186.66	183.67
	Average ENSO		370.33	338.53	31.80

TABLE 6.6 Profit Implications with 5% Discount Rate

		Average Rainfall in Inches	Average Loss ($)	Average ENSO Loss ($)	Difference
$1 per cwt.	None ENSO Winter Precipitation	6.21	-1006.49	-1006.49	0.00
	El Niño Winter Precipitation	7.75	-813.60	-574.79	-238.80
	Neither Winter Precipitation	5.58	-1289.71	-1233.18	-56.53
	La Niña Winter Precipitation	5.30	-916.97	-794.15	-122.82
	Average ENSO		-1057.09	-928.81	-128.28
Per Acre	None ENSO Winter Precipitation	6.21	-0.0101	-0.0101	0.0000
	El Niño Winter Precipitation	7.75	-0.0081	-0.0057	-0.0024
	Neither Winter Precipitation	5.58	-0.0129	-0.0123	-0.0006
	La Niña Winter Precipitation	5.30	-0.0092	-0.0079	-0.0012
	Average ENSO		-0.0106	-0.0093	-0.0013
$50 per cwt.	None ENSO Winter Precipitation	6.21	-50324.28	-50324.28	0.00
	El Niño Winter Precipitation	7.75	-40679.84	-28739.65	-11940.19
	Neither Winter Precipitation	5.58	-64485.32	-61659.03	-2826.29
	La Niña Winter Precipitation	5.30	-45848.54	-39707.47	-6141.07
	Average ENSO		-52854.53	-46440.38	-6414.15
Per Acre	None ENSO Winter Precipitation	6.21	-0.50	-0.50	0.00
	El Niño Winter Precipitation	7.75	-0.41	-0.29	-0.12
	Neither Winter Precipitation	5.58	-0.64	-0.62	-0.03
	La Niña Winter Precipitation	5.30	-0.46	-0.40	-0.06
	Average ENSO		-0.53	-0.46	-0.06
$75 per cwt.	None ENSO Winter Precipitation	6.21	-75486.42	-75486.42	0.00
	El Niño Winter Precipitation	7.75	-61019.77	-43109.48	-17910.29
	Neither Winter Precipitation	5.58	-96727.98	-92488.55	-4239.43
	La Niña Winter Precipitation	5.30	-68772.81	-59561.21	-9211.60
	Average ENSO		-79281.80	-69660.57	-9621.23
Per Acre	None ENSO Winter Precipitation	6.21	-0.75	-0.75	0.00
	El Niño Winter Precipitation	7.75	-0.61	-0.43	-0.18
	Neither Winter Precipitation	5.58	-0.97	-0.92	-0.04
	La Niña Winter Precipitation	5.30	-0.69	-0.60	-0.09
	Average ENSO		-0.79	-0.70	-0.10
$100 per cwt.	None ENSO Winter Precipitation	6.21	-100648.56	-100648.56	0.00
	El Niño Winter Precipitation	7.75	-81359.69	-57479.30	-23880.38
	Neither Winter Precipitation	5.58	-128970.64	-123318.07	-5652.57
	La Niña Winter Precipitation	5.30	-91697.08	-79414.94	-12282.14
	Average ENSO		-105709.07	-92880.76	-12828.30
Per Acre	None ENSO Winter Precipitation	6.21	-1.01	-1.01	0.00
	El Niño Winter Precipitation	7.75	-0.81	-0.57	-0.24
	Neither Winter Precipitation	5.58	-1.29	-1.23	-0.06
	La Niña Winter Precipitation	5.30	-0.92	-0.79	-0.12
	Average ENSO		-1.06	-0.93	-0.13

APPENDIX

APPENDIX A: Data Descriptions and Processing Methods

The data sets utilized in this analysis were gathered from a variety of sources. The first and primary data obtained and scrutinized was the herd characteristic data. This data contains a variety of cattle characteristics collected from the R-100 Registered Hereford Herd owned and maintained by the Apache Indian tribe at San Carlos, Arizona. This data required an obscene amount of careful investigation in order to draw out the information needed to conduct this study. The arduous task of cleaning the data began with compiling a number of separate files to create a user friendly data set that could be used for exploratory regression analysis as well as calculating informative statistics about the herd. The following paragraphs explain the processes involved with the cleaning of the herd characteristic data.

The data compiled in All Calf Data is a subgroup of a file (Calf Records 76 to 89) that records the calf identification number, line, sex, sire identification number, dam identification number, age of the mother, breed past, a birth weight and weighing date, a third month weight and weighing date, an eighth month weight and weighing date, a twentieth month weight and weighing date, along with other various characteristics such as height and condition scores that correspond to the weighing dates.

The initial data set (All Calf Data) utilized to begin exploratory regression analysis consisted of 1,585 individual calf observations born between the years 1980 and 1989. All calves belong to the registered Hereford Herd of the Apache Indian Tribe at San Carlos, Arizona. The year 1987 is excluded from all of the following data sets used to construct and organize other available data due to an absence of data due to personnel .

at the University of Arizona on leave (Don Ray). An additional observation (ID# 88339) was dropped due to incomplete data in required fields, resulting in a final sample size of 1,584 observations. Master Sheet is a clean version of the All Calf Data file used for further exploratory regression analysis.

Each individual calf observation in the data set is comprised of a five digit identification number (tattoo) in which the first two numbers of each identification number reveal the year in which the calf was born. Along with the individual identification numbers, the recorded data includes gender, birth weight, birth date, a third month weight and weighing date, an eighth month weight and weighing date, a twelve month weight and weighing date, and a twenty month weight and weighing date. All weights are recorded in pounds.

The recorded weights of the calves at the various time periods made it possible to calculate the weight gain of each individual calf within the data. The weight gain of each calf for various time periods is calculated and compared to the various climate measures to identify any correlation between weight gain and the present climate conditions at that time. The assumption is that with more annual rainfall during the grazing months, there will be a significant increase in weight gain from birth through the twentieth month.

In the original All Calf Data file, gender is represented by an indicator variable where sex = 1 if male and sex = 2 if female. Gender is redefined to sex = 1 if male and sex = 0 if female in Master Sheet in order to perform exploratory regression analysis. The indicator variable for gender is redefined to sex = 1 if female and sex = 0 if male for final estimation procedures as well as to avoid any discriminatory bias. There are a total of 789 males and 795 females calves present in the data set.

In addition to the calf data, other data sets became available that offered further insight to the San Carlos cow-calf ranching operation. Among these data files were spreadsheets that linked the sires and heifers to the offspring of the original calf data set. These data also had recorded identification numbers for the sires and heifers in which the first two digits of each identification number represent the year in which the cow was born. This proved to be very useful when calculating total number of head on the range per year, the number of calves, bulls, and heifers culled per year, along with many other various herd characteristics.

The first step in determining the number of cattle on the range per year was to determine how many bulls, heifers and calves there were present in the base year. This number does not account for culled cattle or cattle that are absent due to other unobserved circumstances. Calculating a base number for the number of cattle on the range per year was accomplished by breaking the data into categories and accounting for each individual bull, heifer, and calf.

Calculating the number of bulls present each year proved to be the most difficult to calculate due to missing identification numbers of the bulls that produced calves in each year. Another complicating factor is that each bull is bred several times and can produce several calves. For this reason, the number of calves with unidentifiable fathers was divided by the number of identifiable bulls to get an approximation of the number of bulls required to produce the calves with unidentifiable fathers. This number is added to the number of identifiable bulls and rounded to the nearest whole number to produce an approximate number of total bulls present in each year. The estimate of total bulls has some error. This error is acceptable for this study due to the fact that the bulls are kept separate from the other cattle in order to discourage inbreeding.

The number of heifers per year was calculated by counting the number of heifers that gave birth each year. All heifers with missing identification numbers are counted once. This is because for each calf their must be a mother and a father. Heifers producing more than one calf per year are a rare occurrence in the data. Accounting for the number of calves per year was easily determined due to the availability of data.

After combining all the available data resources, it was possible to develop a method to trace the activities of the herd. The year 1979 is used as a base year being that 1980 is the first year of available calf data. 1979 is a good base year because there are no bulls or heifers with unknown ages. Subsequent years contain some entries in which there is no recorded identification number. By having the first two digits of each identification number represent the year in which each bull, heifer, and calf was born it is possible to determine the ages of all cattle against the time period 1979 through 1989 (excluding 1987). The interesting phenomenon that occurs within the herd is that the male and female calves produced each year become the fathers and mothers of the future calves.

Once a total number of head on the range per year was determined, the next process was to determine how many cattle were culled or sold, remained in the herd, replaced, or perished to obtain a number to represent the stock of cattle on the range for a given year. This was accomplished by grouping the cattle by year and age to determine the number of cattle added to a certain age group or absent from a certain age group. There were several years in which the ages of the cattle could not be ascertained due to missing identification numbers. These cattle were placed into an unknown category and included as part of the total head figure. Although the age of some cattle was unknown, they still existed in the data. Total head count numbers were calculated by summing the number of kept bulls, heifers, and calves present each year and subtracting the number of culled cattle. This is based on the assumption that the herd is only sold off. No new cattle are purchased and brought into the herd.

Region specific precipitation and temperature data was also collected to serve as control variables for climate conditions that existed in the San Carlos area for the years 1979 through 1980. Precipitation data is available in monthly averages and is recorded in inches for a number of years. Monthly temperature averages are also available for the targeted years and are measured in degrees Fahrenheit. The climate data is available on the WRCC website and is incorporated throughout the herd data files to check for correlation between herd characteristics and variations in the relevant climate variables.

Cool season and warm season precipitation values were calculated from the available precipitation data. Cool season precipitation represents rainfall between the months of November and April while warm season precipitation represents rainfall for the period between May and October. Cool and warm season precipitation are important variables to account for due to the fact that most calving occurs in either the spring or late fall, and precipitation is a crucial element in successful forage production.

Along with the precipitation data for the San Carlos region, Southwestern USA Linear Regression and Neural Network Precipitation Reconstructions (Ni et. al.) were acquired to serve as a proxy for precipitation and to use as a comparison against the weather station precipitation measures. The precipitation reconstruction data is available for the seven different climate divisions of Arizona and the eight climate divisions of New Mexico for the years 1000 through 1988 and represents reconstructed cool season precipitation. The particular data used in regression analysis represents 1000 year reconstructions of cool season (November – April) precipitation for Arizona Climate Division #4.

The original reconstruction data is measured in millimeters. Millimeters were converted into inches to provide a standardized unit of measure consistent with the calf weight measurement of pounds. Arizona climate division number four is used to represent Gila County which is where San Carlos, Arizona is located and where the herd thrives. The reconstruction data serves a control proxy for precipitation being that it is produced from the trees amongst which the cattle graze and rest beneath. This situation creates a more natural relationship between the environment and its inhabitant.

Finally, El Niño Southern Oscillation (ENSO) data for Arizona precipitation was obtained from the Institute for the Study of Planet Earth (ISPE) and from the Western Regional Climate Center (WRCC). Three sets of Southern Oscillation Index (SOI) values were collected and compared to check for uniformity across the data. The first data set from ISPE contains SOI values and precipitation values for Arizona Climate Division #4, while the other two data sets are representative of the entire state of Arizona. One is from

ISPE and the other is from WRCC. The two data sets from ISPE have SOI values for the years 1896 through 2002 while the WRCC SOI values are for the years 1933-2003. The Arizona wide ENSO forecast and winter precipitation data was used instead of the more localized climate division #4 data in order to make the results more generalized and to provide a clearer presentation.

These data relate winter precipitation values to the SOI which categorizes years into El Niño, Neither, and La Niña years based upon the year's average SOI value. El Niño years are represented by a SOI value less than -0.5. Neither years are those years that have a SOI index value between -0.5 and 0.5, while La Niña years are represented by SOI values greater than 0.5. These data are used in model simulations to serve as probability measures for the occurrences of El Niño and La Niña years.

All three data sets are linked to the same winter precipitation values collected from the WRCC website. Each year's SOI value is the average value for the months June through November. Each SOI value represents the year prior to the winter precipitation year. For example, the SOI value for 1980 corresponds to the total precipitation for October of 1980 through March of 1981.

APPENDIX B: The Logistic Based Growth Function

The logistic based growth function utilized in this analysis is based on the logistic model derived in Conrad and Clark, 1987. For simplicity, it is assumed that the resource under consideration can be described by a single state variable. In the absence of harvesting, the dynamics of the resource stock can be described by,

(1) $F(S_t) = S_{t+1} - S_t$,

where $F(S_t)$ is the logistic equation which represents the size of the resource stock at time t denoted by S_t. The simplest form of the logistic model is expressed as,

(2) $F(S_t) = rS_t(1 - S_t / k)$,

where r is the intrinsic growth rate and k is the environmental carrying capacity.

In the presence of harvesting, the rate of change within the resource stock must reflect growth and harvest. Equation (1) is modified and expressed as,

(3) $F(S_t) - Y_t = S_{t+1} - S_t$,

where Y_t is the rate of harvest measured in the same units as the resource stock S_t. For this analysis, the resource stock is measured in terms of animal units.

The discrete-time model in equation (3) can be expressed as,

(4) $S_{t+1} = G(S_t) - Y_t$,

where $G(S_t) = S_t + F(S_t)$.

Substituting R_t for $G(S_t)$ yields,

(5) $S_{t+1} = R_t - Y_t$, so

(6) $R_{t+1} = G(S_t)$, and

(7) $S_t = R_t - Y_t$,

where equations (6) and (7) define a spawner-recruit model and S_t is the spawning escapement in year t, R_t is the recruitment to the population in year t, and Y_t is the harvest extracted from R_t.

Thus, since $G(S_t) = S_t + F(S_t)$ and $F(S_t) = S_{t+1} - S_t$, the logistic based growth function utilized in this analysis is represented by,

(8) $G(S_1) = S_1 + rS_1\left(1 - \frac{S_1}{k}\right)$,

where $G(S_1)$ represents the growth of the cattle biomass measured in animal units, S_1 represents the initial cattle biomass measured in animal units, r represents the biomass intrinsic growth rate that quantifies how much a population can grow between successive time periods, and k represents the carrying capacity of the range in terms of animal units.

APPENDIX C: The Value of Climate Forecast Information Simulation

The simulation designed to determine the value of climate forecast information is an Excel spreadsheet that can be manipulated to calculate stocking rates and growth rates based on different levels of climate forecast information. The simulation was created to serve as a tool for systematically analyzing the relationships between the variables in the stocking rate decision and to quantify the value of climate forecast information as it pertains to this range cattle stocking decision. The value of climate forecast information simulation can also demonstrate how climate variability ultimately impacts ranch profitability.

The simulation utilizes historical winter precipitation data for Arizona along with ESNO data to represent climate forecast information. The parameters k, r, Δ, and α, in the dynamic stochastic model can be manipulated within the worksheet to analyze marginal changes in the stocking rates with different levels of climate forecast information. The calibrated dynamic stochastic two-period model is simulated using historical winter precipitation data and ENSO forecast data to determine the value of climate forecast information in the range cattle stocking decision.

To begin the value of climate forecast information simulation, a sample of 106 years of historical Arizona winter precipitation data for the time period 1896 to 2001 was categorized into ENSO events based upon Southern Oscillation Index (SOI) values for each year. El Niño years are represented by a SOI value less than -0.5, La Niña years are represented by a SOI value greater than 0.5, and Neither years are those years that have a SOI value between -0.5 and 0.5. The SOI value ranges are set by the researcher and are predefined for this study. A further explanation of this data can be found in APPENDIX A: Data Descriptions and Processing Methods.

El Niño years account for 31.13 percent of the sample, Neither years account for 46.23 percent of the sample, and La Niña years account for 22.64 percent of the sample. The historical Arizona winter precipitation distribution along with the winter precipitation distribution for each ENSO state can be seen in Figures 6.2, 6.3, 6.4, and 6.5.

The purpose of dividing the historical Arizona winter precipitation data sample into the various ENSO states is to compare the implications that different levels of climate information have on the biomass growth in terms of animals units and how the stocking decision impacts the profitability of a cow-calf ranching operation. If ENSO state forecasts are the only type of climate information available to a rancher, can this information improve management strategies when the precipitation for a given year is an independent draw from the ENSO state of the given year and the separate distribution of each different ENSO state is known? In order to address this question, it is necessary to evaluate changes in profits at different levels of climate forecast information.

The expectation of Z utilized in the optimization represents the different types of climate forecast information available to the rancher. In the baseline case, the rancher does not have ENSO forecast information and $\overline{Z}$ is the historical average winter precipitation. With perfect information, $\overline{Z}$ would be equal to the actual winter precipitation for a given year. The quality of $\overline{Z}$ completely represents the state of information of the rancher. With perfect ENSO forecasts, the individual ENSO state distributions can be utilized, instead of the entire historical winter precipitation data. If the rancher has ENSO forecasts, the rancher can set $\overline{Z}$ for El Niño years equal to the average winter precipitation for EL Niño years, the $\overline{Z}$ for La Niña years equal to the average winter precipitation during La Niña years, and the $\overline{Z}$ for years without El Niño or La Niña events equal to the average for these years.

In order to correctly evaluate the profit and stocking implications of having different levels of climate forecast information, the function parameters of the dynamic stochastic model must be adjusted. First, α must be adjusted to represent the average Arizona winter precipitation. To evaluate the profit implications of different climate forecast information in the presence of different discount rates, the carrying capacity and the intrinsic growth rate are adjusted. The calibrated parameters for the dynamic stochastic two-period model adjusted for the various discount rates utilized in this analysis are summarized in TABLE 6.4.

The value of information can be quantified by evaluating an average optimal stocking rate using the expected value of precipitation levels and comparing them to an optimal stocking rate evaluated at actual precipitation levels. The stocking rates derived with actual precipitation levels provides some additional information that can be incorporated into the stocking decision, while stocking rates derived from expected precipitation levels represent a base line scenario.

The following function is utilized to evaluate the profit implications or changes in profits as the difference between having ENSO climate information and the knowledge of average rainfall from historical winter precipitation data. The difference between the different levels of climate forecast information represents the profit implications associated with imperfect information. The change in profits is evaluated as the difference between the rancher's profits when the rancher stocks according to an expected amount of winter precipitation but receives the actual amount of winter precipitation and if the rancher had stocked the amount appropriate for the actual amount of winter precipitation and received the actual amount of winter precipitation. The change in profits at different levels of climate forecast information for the stochastic dynamic two-period profit function is represented by,

$$(1)\ \Delta\pi = \pi\left(S\left(\overline{Z}\right), Z_{Actual}\right) - \pi\left(S\left(Z_{Actual}\right), Z_{Actual}\right)$$

$$= S\left(\alpha Z_{Actual}\right) - S\left(\alpha \overline{Z}\right) + \frac{\left(\alpha Z_{Actual} G\left(S\left(\alpha \overline{Z}\right)\right) - \alpha Z_{Actual} G\left(S\left(\alpha Z_{Actual}\right)\right)\right)}{\left(1+\Delta\right)},$$

where $\Delta\pi$ represents the change in profits in terms of animal units, $\overline{Z}$ represents the expected value or average precipitation value of 6.21 inches based on the historical Arizona winter precipitation data, Z represents actual precipitation level for each year represented in the historical Arizona winter precipitation data, and Δ represents either a two percent discount rate or an eight percent discount rate.

Using the function in equation (1), along with the calibrated parameters for the different discount rates, the change in profits can be calculated by evaluating the fluctuations in animal unit production via growth rates and stocking rates evaluated at actual and expected values of precipitation based on historical winter precipitation and ENSO forecast data.

The intuition behind the relationship in equation (1), is to illustrate the premise of "losing less" with better information regarding future precipitation patterns, particularly with ENSO forecasts. Stated differently, the rancher is able to capture greater profits from marginal animal unit increases in the cattle biomass and manage resources more efficiently by implementing more efficient stocking rates evaluated at better averages calculated from ENSO forecasts. The ENSO forecast information provides a more accurate expected value of precipitation than that of the historical Arizona winter precipitation or none ENSO information. The rancher can optimize expected profits according to ENSO distributions which provide a more accurate measure of average rainfall to use in the stocking decision.

For the baseline case of no ENSO forecast, the simulation applies equation (43) to each year of historical Arizona winter precipitation data using the average historical winter precipitation as $\overline{Z}$, and the historical winter precipitation value for that year as Z_{Actual}. The average over all years provides the average loss to the rancher due to having only the average winter precipitation as opposed to perfect information. This process is repeated for the ENSO forecasts, with $\overline{Z}$ replaced with the average winter precipitation value for the appropriate ENSO state. This provides the losses that the rancher faces if they had perfect ENSO forecast information compared to perfect information forecasts. Because the rancher with ENSO forecasts has more information than the rancher with only the aggregated average, the rancher with ENSO forecasts faces less of a loss. The value of the ENSO forecast is therefore the decrease in average losses between the no forecast case and the ENSO forecast case. The availability of better climate information can minimize losses by promoting efficient management strategies that will encourage ranch profitability and viability.

APPENDIX D: Case Study of the San Carlos Ranching Operation

The Registered Hereford Herd of the Apache Indian Tribe at San Carlos, Arizona can be found grazing on the rangelands in the southern tip of Gila County. The White Mountain or San Carlos Reservation was established in 1872. Cattle were first introduced to the region in 1884 by the United States government to serve as beef rations for the occupying Apache Indians. These ration systems marked the beginnings of cattle herds for some Indians. Instead of taking weekly beef rations, some Indians instead chose to save their ration credits until they could draw live cattle. Some of the newly acquired cattle were butchered while others were kept to produce small herds.

In 1886, following the capture of Geronimo and his loyal followers, cattle companies such as the Chiricahua and Sierra Bonita spread through eastern and southern Arizona as Apache raids became extinct. Many of the new cattle operations were running thousands of head through the prosperous rangelands of the region encroaching on reservation lands. The movement towards reservation lands was often the result of drought. Drought had plagued other ranges and made them unsuitable for range cattle production. This marked the beginning of lease grazing on the San Carlos Reservation. Large cattle companies utilized the available rangelands of the San Carlos Reservation to graze cattle for a fee.

During this time, the Soil Conservation Service prepared a report on the natural resources of the San Carlos Reservation. The study found that the reservation did not have sufficient resources to provide adequate substance to support the number of Indians living there.

In 1923, plans to make the San Carlos Indians an independent and self supporting people began to formulate. The reservation lands were stocked with high grade Hereford cattle to encourage an independent and self supporting reservation. By utilizing the available rangelands of the reservation to produce livestock, many felt the San Carlos Reservation could increase incomes and become a self supporting tribal nation.

In 1933, action was initiated to make the tribal herd a registered herd. In 1934, the United States government furnished the reservation with 600 registered Hereford heifers and 30 registered Hereford bulls. This was part of a replacement plan to begin the production of purebred cattle. There was no plan implemented at this time to control and record breeding for registration.

In 1938, all registered cows and purebred heifers were moved to Ash Flat where they were bred by artificial insemination to produce superior range cattle for exclusive use on the reservation (artificial insemination later became discounted as a management practice for beef cattle on the range after 1955). This became the registered herd from which individual Apache tribal members could draw heifers.

The year 1938 marked the end of lease grazing along with the completion of the Soil Conservation Service Report. Nearly all non-Indian permit holders had vacated the reservation grazing lands as groups of Indian cattlemen began organizing into formal cattle associations. The ranges were being designated by the names of the associations or the name of the herd occupying the range. The registered herd provided bulls to the various associations.

In addition to the cattle operations being ran by individual ownership, there were ranching operations being conducted by the Bureau of Indian Affairs and the Tribal Council for the benefit of the entire tribe. Different herds served different purposes for the tribe. For example, the IDS herd was maintained for the benefit of boarding schools. Another tribal herd, the IDT or Social Security herd, was maintained to provide income for those who had no other means of support. The primary beneficiaries of the IDT herd were the elderly, widows, orphans, the blind, and the crippled.

In 1956, a cooperative agreement between the San Carlos Apache Tribe, the University of Arizona, and the USDA was formed. Under the agreement, the tribe handles the management and marketing of the registered Hereford herd or R-100 herd, while the University of Arizona provides technical guidance and maintains a database of research findings.

Today, there are approximately 100,000 acres of grasslands throughout the reservation enshrouded with perennial warm and cool season grasses along with scattered trees and shrubs. The herd survives solely on the available forage that exists on the range No supplemental feeding is administered to the herd. A short breeding season (May, June, and July) allows for the cattle stock to remain in balance with the available range resources. Low stocking rates contribute to the tribe's ability to control grazing throughout the range. Cattle are rotated amongst pastures to ensure sufficient forage and water as well as allowing grazed pastures to regenerate. Proper range management practices along with modest stocking rates have created forage reserves that can carry animals through drought conditions.

During my visit to the San Carlos Reservation, along with Dr. Russel Tronstad and Trent Teegerstrom, the tribe was generating talks on how to restructure the ranching operation of the R-100 herd to meet the changing goals of the tribe. The profits derived from developing a registered herd is the primary concern. Most of the herd has been sold off, leaving the available rangelands with little or no livestock. There are three tribal ranches throughout the reservation that are permitted by the tribal council to hold 3,100 head. Due to current drought conditions and range conditions, some tribal members felt that the current rangelands of San Carlos could only support upwards of 2,000 head.

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