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Psychological Factors in Resource Allocation

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by

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TABLE OF CONTENTS

Table of Figures

Overview

The focus of this project is on a hypothetical scenario where two strangers allocate a renewable resource for themselves, and there are no other exploiters of the resource. Of particular interest are the psychological aspects of this process. A historical and conceptual overview of theory relevant to resource allocation is presented, and some of the concepts are reviewed in more detail to provide a view of current theories regarding the sharing of resources. The discussion of theories of resource sharing, is intended to provide a starting point for general research into psychological aspects of resource sharing with a brief view of how the field has developed. The historical view is important, as it gives a feel for what types of theories and research have been developed, and where to look for various trends in theory on resource sharing.

The most relevant concepts from psychology and sociology consist of a set of empirically documented behaviors dubbed heuristics, which deviate from classical concepts of logical behavior. An overview of heuristics is presented, and several heuristics are described in enough detail to provide a basis for the development of a system dynamics model of resource allocation between two individuals. The system dynamics model is developed to model the actions of two herders who graze their cattle on a common pasture. The developed model includes the heuristics of uncertainty, social value orientation, and temporal discounting, and provides results that are consistent with expectations given the inclusion of these heuristics.

RESOURCE ALLOCATION

Why Study resource allocation?

An incentive for research in resource allocation lies in the vast movement of substance and information throughout world and society. It is important to understand the forces that are changing our world. The distribution of resources on our planet is not spread equally among people but varies throughout countries, societies and individuals. The way in which resources and opportunity for resources are distributed among the people of our planet is sometimes a source of concern. Sometimes a few people are able to hog resource at the expense of others. Additionally, competition for resources can result in resource depletion, or destruction.

Overall resource distribution is an amazingly complex topic since it addresses the movement of every physical and informational resource that humans can share. Theories about the process of resource allocation spread through three fields: economics, psychology, and sociology with the latter two sometimes being grouped as social psychology. Most research on resource allocation has been lead by developments in economic theory, with inclusion of social psychological theory as an attempt at improvement. Although economic rules may often successfully describe resource allocation, widespread social and psychological processes appear to be the underlying cause of the economy. That the economic variables of supply and demand are something that people produce is an illustration of this point. Applying information on psychological and sociological processes to resource allocation should result in a more interesting and diverse understanding in this area. Steps toward a more diverse view in economics have been taken, but this movement is still limited by much of mainstream economics.

Project goal

The primary focus of this project is on discerning psychological and social variables and processes that are potentially significant in resource distribution, with special interest in a one-on-one interdependent relationship between two strangers. Because only two people are involved, the behavior exhibited may include effects that are not as prevalent in large groups. In addition, the dyadic relationship is a simplification that is hoped to allow for an increased development of the psychological dynamics of the situation. Reviews of historical and theoretical perspectives will provide a background and introduction to the problem. A review of relevant research will be presented, and the usefulness of the gathered information will be assessed for possible applications to building a dynamic model of a hypothetical dyadic situation. Tentative systems dynamics models will be developed using evidence from social psychology and economics. Since the present project is a limited research project, a thorough system dynamics treatment will not be done, but it is hoped that this project will provide, a basis for further development in that area. As such, it is the researchers aim to provide an exploration of any theoretical and empirical findings that may be relevant.

Scenario to be modeled

I was inspired partly by Garrett Hardin’s “Tragedy of the Commons” example, to explore the modeling of a herding scenario involving two people(10). Garrett Hardin created a scenario of how resources would be allocated in a common pasture that many people have free access to. Alternatives to the classic type of rationality that Hardin uses in his scenario will be introduced as possible decision mechanisms for the herders. The scenario envisioned, like Hardin's example, is of a pasture where cows can be grazed. However, unlike the example Hardin gives there are only two people who have access to the pasture. There is no connection between the two herders; they are strangers who are interdependent upon the same field of grass as the sole means to feed their herds. The pasture cannot be claimed by one, or the other, and cannot be split geographically because the concept of land property is not present or not practical. Grass on the pasture is a renewable resource that replenishes itself with time, and is depleted by the grazing cattle. The herders profit by selling their mature livestock, which have a constant market value. They individually control their herd sizes, having the opportunity to increase or decrease their herd size at will. Because of the possibility of overgrazing the limited pasture, the herders will remain interdependent. This scenario, which will be referred to as the "model scenario," is an object against which the applicability and adequacy of various theories will be explored. The questions are: How will the herders modify their herd sizes, and how can this behavior be understood? When, and why will the pasture become severely overgrazed? These questions reflect an interest in the nature of resource allocation, and problems with resource depletion.

A very simple concept in the model scenario is that the herders have the single option of adding or removing cattle from their herds. Thus, regardless of how the herders make their decisions, the resulting action can only be the addition or removal of cattle. There are obviously a multitude of possible outcomes and behaviors in real life situations like this. Since there are only two herders, certain aspects of the situation simplify. For example, there is only a single dyadic relationship, whereas the behavior of a herder from a group of 6, theoretically, might be affected by the behavior of the 5 other herders, or possible dyadic interactions for the 15 unique pairs of herders. The model will only have to have a deal with considerations of the effects of each herder on the other, rather than considering the actions of a large population.

Characteristic problems with a common pool resource (CPR)

A basic concept which relates to resource distribution is the idea of Common Pool Resources. Common Pool Resources(CPRs) are resources that are shared by more than one entity. Entities exploiting a CPR are subject to a conflict between individual and group benefit. This conflict occurs when the resource is limited in nature and when the entities have at least limited control over how much of the resource they personally exploit. The limited nature of most resources means that some entities may exploit the resource at the expense of others. A classic and often identifiable scenario occurs when a greedy member takes more than their equal share of dessert, and the remaining members(generally disapprovingly) obtain less. Much more frightening scenarios involve the consumption of natural resources and the overpopulation of the planet. Such conflicts between individual and group benefit occur abundantly in real life. Take our highway systems as an example. The public interest choice would be to car pool for an overall reduction in traffic, pollution, and fuel consumption. The self-interest choice may be to drive one's own car for convenience. Since the negative effects from one additional car will not have a great impact when there are millions of cars, a single self-interest choice does not have a high price. However, when everyone acts in self interest the highways become crowded, the air more polluted, and the oil reserves more depleted. Everyone acting in self interest would produce outcomes that most people would find undesirable.

Many CPRs that have received public attention are fishing banks around the world. An article in the Boston Globe newspaper recently lamented how the Atlantic sea scallops are routinely harvested at 3 years old, before they reach reproductive capacity when they spawn millions of baby scallops every year(18). Because the scallops are harvested so young, billions of potential dollars are being wasted. Because the scallops belong to whoever catches them first, a fisherman does not have a strong incentive to try and let the scallops mature since another fishing boat can come along and take the profits. This exemplifies the dilemma that is common in CPRs. The ocean is a good example of a CPR because there are no personal property rights, although international agreements and local regulations exist which thwart, but do not eliminate, accessibility. National forests, and many other CPRs, are also managed by regulators. Rules are devised to limit the potentially shortsighted actions of exploiters of the resource. However, the management of the ocean resources has not avoided problems common to CPRs. Many fishing banks have been closed, to allow the fish population to recover after having been over-harvested.

Social Dilemmas and Commons dilemmas

Resource allocation situations involving a conflict between individual and group benefit have been termed social dilemmas. Key characteristics of social dilemmas are that 1) a participant's self-interest choice results in more gain, or less loss than a public interest choice, and 2) the participants benefit more as a group if everyone acts in the common interest(8). Social dilemmas involving the overuse of natural resources such as space, energy, and ecosystems are often called commons dilemmas(8). All social dilemmas have an element of interdependence between the outcomes that participants attain. Often, it is when the limitations on a resource increasingly affect the situation that participants' interdependence increases. For example, on highway systems with low traffic it may be possible for everyone to drive their own car without causing a traffic jam. However, when the traffic volume is already heavy an increase in single passenger cars could cause commuting to become impractical, and thus provide a detrimental outcome.

Hardin illuminates the commons dilemma

The idea of the commons dilemma was brought to greater public attention by Garrett Hardin's 1968 article "The Tragedy of the Commons"(10). In this article he highlights the problem of a limited earth with a growing human population as a commons dilemma(10). It can be argued that the earth and its resources are limited. Meanwhile the human population continues to increase drastically. According to this line of reasoning, the amount of interdependence among people for resources increases, with decreasing resources and increasing population. Widespread self-interest choices can have a detrimental effect on the size of resources. The decimation of certain depletable resources such as oil reserves and ecologies may result in disastrous effects for humanity. Thus, understanding and mitigating the processes responsible for the use of these resources is important for the long-term survival of humans. There are many critical resources that humans use. Some of these resources are oil, energy, clean water, clean air, physical space, and food. The earth, consisting of many resources, is a CPR on a larger scale. The exploitation of the earth as a whole describes a larger social dilemma. Hardin's article sparked interest and research in commons dilemmas and social dilemmas.

A particular example of a commons dilemma that Hardin gives became a well-known example. Imagine a pasture for grazing cattle that is open to all who wish to graze their cattle there. Pastures such as this were often called commons, and located in the center of New England towns for the benefit of the local cattle owners. Ironically I witnessed that today the Boston Commons contains a plaque stating that one of the common's functions is to provide for the grazing of cattle. By Hardin's logic it is in the benefit of each herder to graze as many cattle as possible on the pasture since the more cattle they graze, the more money they make. The cost of overgrazing is shared by all of the herders, but each herder receives the full benefit from selling each cow that they graze on the pasture. Since the cost of adding an extra cow to an individual's herd is shared among all of the herders, the self-serving decision of each individual herder is to add cows to their herd. The end result of this scenario is that cows are added to the pasture until the pasture is overgrazed, thus resulting in a tragic ending.

Hardin expresses this scenario in terms of the utility a herder receives by adding another animal to their herd(8):

> This utility has one negative and one positive component.
>
> 1) The positive component is a function of the increment of one animal. Since the herdsman receives

> all of the proceeds from the sale of the additional animal, the positive utility is nearly +1.
> 2) The negative component is a function of the additional overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all the herdsmen, the negative utility for any particular decision making herdsman is only a fraction of -1.

In these terms, the positive utility of adding one more cow represents the benefit generated by the sale of that cow. The negative utility is the cost of overgrazing of the pasture; a loss that is shared by all of the herders since each cow would then have a diminishing amount of grass to eat. Hardin states that given conditions 1) and 2):

> Adding together the component partial utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another, and another....

Thus, Hardin concludes that the result of such a scenario would be the destruction of the pasture by overgrazing, and the starvation of cattle. When the commons has been destroyed, a "Tragedy of the Commons" has occurred.

Each herdsperson in Hardin’s scenario is a “rational actor” performing actions in self-interest. The idea of the rational actor can be traced back as far as 1776 in Adam Smith's "The Wealth of Nations" in which he described his theory of the "invisible hand"(7). Adam Smith theorized that each person acting in their own best interest is the solution for creating a healthy economy. It is likely that the way Garrett Hardin's "Tragedy of the Commons" article blatantly refutes this long-held paradigm contributed to the amount of attention that the article received. In Garrett Hardin's tragedy of the commons scenario, he assumes that all of the herders choose to add a sheep according to a rational decision to maximize personal gain. Although Hardin did not change the classic model for human behavior in economics, he came to a different logical conclusion than did Adam Smith. Hardin's conclusion that such scenarios result in disaster has received only limited empirical support(20). However, the logic of Hardin's argument clearly shows a major flaw in Adam Smith's "invisible hand" theory where the cumulative self-serving acts of individuals create a healthy economic situation.

Economic view of behavior

Most economics is based on certain ideas about human behavior that are heavily influenced by what I view as western ideals of rationality. Hardin's example in the "Tragedy of the Commons" is illuminative of these ideals. The argument given by much of economics is that people assess the costs and benefits of potential actions(7). The benefits minus the costs is the total utility for an action. If there are several possible actions, then the action with the greatest utility is chosen. This description of utility is easily amendable to describing monetary costs and benefits, although motivations such as love, or desire for leisure have also been included in economic models(1). In economics, utility applies only to the self, and thus considers people as acting in pure self-interest(1). These rules of what economists often term "rational behavior" have been a mainstream model of human decision making in economic models(4)(1). For simplicity I will use the term "economic rationality" to refer to this model of behavior. Economic rationality includes three important characteristics: 1) utility is maximized(optimization), 2) actors have unlimited cognitive capability(unbounded rationality), 3) actors are individualistic, and have independent tastes and preferences(5). The third condition implies a lack of herd-like phenomena, or "monkey see, monkey do" behavior. Economic rationality does not specify what is desired, but is a model of the method by which people attain what they desire.

Economic rationality is predictive, but has weaknesses. The idea that humans pursue utility in the way that bugs pursue a light at night is useful because it is clear and easily translates into predictions of human behavior. The assumption that people are truly instruments of economic rationality is questionable. There has been evidence that decisions are influenced by factors not included in, or contradicting the rules of economic rationality. A few examples of such effects are time to payoff(23), social influences(24)(15), and skewed cognition of probabilities(9). One of the problems with the more realistic definitions of economic rationality which have been developed is that they often don't have clear testable predictions, and make analysis more difficult due to their complexity(1). There are several different criticisms of economic rationality that will be reviewed. Criticisms relevant to each of the rules of economic rationality will be presented. Most of economics has relied on the rules of economic rationality, but alternate and revised models are now being used as well(5)(4)(15). Economic rationality has provided a base theory, which many theories have complemented, or diverged from. In a similar vein, this report starts with the concept of economic rationality before expanding to include further descriptions of choice behavior.

Difficulty with defining certain factors.

A general problem with quantifying effects and factors is inherent in model development of human behavior. When considering that people's only goal is to make money, the rules of economic rationality can easily be applied to yield a mathematical maximization of a problem, since money is a physical substance and can be counted. Problems arise when a person desires non-monetary and especially non-physical categories of things. For example what kind of cost would one numerically assign to the stress related to a particular job, and how would that valuation compare to the person's valuation of money? I would expect that a person considering two jobs, one pleasant yet low pay, and one high paying but stressful would consider both monetary benefits and the stress factor in their decision. To apply the rules of economic utility would require placing a numeric cost value on the expected stress, and a numeric benefit to expected monetary gain. How to do that is somewhat of a mystery. When dealing in only one factor such as either stress or money this problem simplifies to relative quantifications. However, trying to compare two different factors can be somewhat like comparing apples to oranges; they are just different things.

It is not a trivial assumption to assume that all factors can be reduced to a common psychological currency, which presents comparable values to a person. Yet this is the assumption that is inherent in the idea that humans assess the costs and benefits of all the different possibilities and then add them together to find the utilities for each decision. In order to add two things together, they must be reduced to a common unit of measurement. This technical problem is a barrier in model development of human behavior, and economic utility is certainly not unique in this aspect. Perhaps it is because this is a general problem with modeling human behavior that I have not seen this type of criticism in the articles that I have read that critique economic rationality. A redeeming argument that I was taught in System Dynamics courses at WPI, is that behavior can still be reproduced by models, even if the numerical assignments are somewhat arbitrary. A few examples of factors, which may be difficult to quantify, are beliefs, laziness, desire for human companionship, compassion, guilt, and desire to conform. I think that an appropriate term for utility that includes such factors is "soft utility" and a term for monetary utility as "hard utility". The difficulties of dealing with soft utility are an impediment to the economic rationality model.

Social aspects of behavior have been underplayed in economic rationality

Perhaps, because of the difficulty in dealing with soft utility, it is not surprising that theorists in economics have resisted the inclusion of more sociological and psychological aspects of decisions(4)(15). Although the application of models of decision making are an essential part of economics, I believe that the problem of how people choose falls more naturally in the field of social psychology. The choice behavior of people seems affected by both psychology and social setting. Thus, social psychology should provide important answers about how people make choices. Because of the deep roots of ideas of rationality, the sociology and psychology of decision have been, in part, shaped by these ideals. Thousands of studies in social psychology are focused on whether the participants behave according to the rules of economic rationality and choose the choices that will bring the individual the maximum benefit(7). I have observed that, in many of the arguments against economic rationality, inconsistencies with measured behavior have been framed as deviations from economic rationality. More sociological and psychological evidence has been included in more recent economics. However, a common sentiment exhibited in criticisms of economics is that although work has been done to include sociological and psychological factors, this movement is not large enough, or should be developed faster(5)(4)(15).

The lack of some social factors in economic rationality has been criticized, because the economic behavior of institutions and groups is affected by social factors such as norms and values(15). Criticisms within economics of the assumption that people act individualistically and have independent tastes and preferences focus on the role of institutions and group behavior(5). Chris Doucouliagos claims that this weakness is the major failing of economic rationality(5). Martin Roderick argues for “a more sociological approach to organizations”(15). The criticisms of the assumption of independent tastes and preferences are summarized as: “[1] agents may not act individualistically, and [2] agents' tastes and preferences are neither exogenous nor independent”(5). These criticisms reject the notions of economic rationality that participant’s desires are not affected by other people. It has been contended that the concept of economic rationality is based more on cultural beliefs than empirical evidence(7).

Contained in the idea of economic rationality is that rational entities are completely selfish, and only cooperate when the utility for doing so is greater than for other available options. However, the idea that humans inherently act only in self-interest has been challenged. People will cooperate even in the absence of personal payoff(7). For example, subjects in a study often cited "group welfare" as the cause of their cooperation(7). This debate seems somewhat epistemological. Philosophically, it is hard to distinguish between self-interest and lack thereof, because a seemingly selfless act could be performed for internal rewards. This problem seems to fall somewhere between philosophy and social psychology. However, because social and psychological factors may be underplayed in economics, economic theory may present a picture of behavior that seems selfish.

Thinking is not effortless: "bounded rationality"

The theory of economic rationality assumes that people have an infinite amount of processing power or "unbounded rationality". Unbounded rationality is implicit to economic rationality because the required process of adding all the costs and benefits for each possible decision is not specifically bounded by the rules of economic rationality. In many contexts, the theory that people have unbounded rationality works well, but there is also abundant evidence that this hypothesis is inadequate for many situations. When there are a great number of possible choices, the amount of time and effort necessary to consider every possibility may be prohibitive or impossible for humans. Some economists have tried to compensate for this problem with through theories of what has been termed "bounded rationality". Herbert Simon started work in the 1950s that led to the development of theories of bounded rationality(4)(12)(1). Bounded rationality is based on the concept that there are physiological limits to human cognition, and that cognitive exertion is a cost that it is necessary to recognize. Just imagine that with unbounded rationality everyone could correctly solve the most difficult problems of theoretical mathematics and quantum mechanics. In addition, no one would ever make a mistake balancing their checkbooks. Theories of bounded rationality acknowledge that there is a tradeoff between cognitive effort and judgmental accuracy. Unfortunately, the trade off between cognitive effort and judgmental accuracy has been ignored by much of economics that could find it relevant and useful. As John Conlisk puts it "Experimental and selected other economists recognize the tradeoff, but it tends to be pushed out of sight in economics by the emphasis on unbounded rationality"(4).

Bounded rationality now represents a whole class of theories that reject the economic rationality notions of maximization as well as unbounded rationality. Bounded rationality bars the possibility of maximization, so the two are mutually exclusive. The importance of this distinction is that unbounded rationality does not require maximization. The ideas behind theories of bounded rationality are summarized by Chris Doucouliagos with the following three components: "[1] there are cognitive limitations to rational choice; [2] agents adapt but do not optimize; and [3] agents are not maximizers, they are satisficers."(5). In component [3] Doucouliagos means that people tend to exhibit the effort necessary to attain a satisfactory level of achievement rather than to maximize their gain. In component [2], to adapt is like finding a short-term solution over and over again rather than finding the maximizing solution when a possibility is first encountered. Thus, adaptation implies iterative behavior, whereas maximization is a calculation that is performed only once. Adaptation has no implication for maximization over time, or lack thereof. Adaptive behavior may or may not result in maximization over time, or maximization as the final result. However, satisficing behavior clearly implies that maximization may not be a goal, and therefore implies that the adaptive behavior is influenced by the level of achievement that is satisfactory. A summary of bounded rationality by John Conlisk supports at least the first two of these three components(4). Satisfaction and adaptation are behaviors that are distinct from logical functioning, and, in addition, they contrast with the ideas of maximization proposed by economic rationality. That people are able to become satisfied means that they may not be concerned with economic (or otherwise) utility beyond a certain point(5). Optimization is synonymous with maximization, which is a mathematical technique used to determine the maximum possible outcome under given constraints. Optimization is related to cognitive ability because it is a calculation. Imperfect cognitive ability confounds the inference of optimization, since there can be only one solution set that is optimal. The concept of adaptation fits better with imperfect cognitive ability, since precise or immediate optimality is not a requirement. Making a decision that considers the effort of reasoning as a cost can be construed as a constrained optimization, although this approach runs into difficulties with infinite regressions, and does not capture the full possibilities of adaptation(5)(4).

Reasoning and Biases coexist.

There is a great deal of evidence supporting bounded over unbounded rationality. Empirical evidence from experiments with individual subjects shows a large number of deviations from unbounded rationality, and that many of these deviations are systematic(4). Several examples of deviations from unbounded rationality are: discounting the value of future payoff(23), overweighing of small probabilities(9), the underweighing of large probabilities(9), and making different decisions based on whether one's perspective is on potential gain or loss(6). That many of these deviations are systematic is important from a theoretical standpoint since theories explain specific patterns in events. Many of the experiments test the type of cognitive abilities assigned to people in economic theory, and show that people often do not do well on such tests(4). The number of experiments documenting these deviations, often called "heuristics and biases", is so numerous that a significant number of books and survey papers have been written to review the evidence(4). Many experiments also show that human subjects can attain accurate reasoning, and that practice can improve accuracy(4). However, heuristics and biases are not fragile effects, but are pervasive, and experiments have shown that attempts to get subjects to become unbiased typically enjoy limited success in attenuating the biases(4). Evidence also suggests that the magnitude and nature of deviations from unbounded rationality are systematically related to economic conditions such as the cost of cognitive effort, incentives, and experience(4).

Heuristic Judgment Theory.

Although consisting of a small fraction of the models in economics, there are a significant number of models which allow bounded rationality(4). These models attempt to compensate for various biases in human decision-making, and spread in many directions like the biases they attempt to describe. Heuristic Judgment theory is a guideline for applying heuristics to human decision making models(11). Although this theory appears more suggestive than definitive, it is a decent proposal for a way to classify the process. This model divides the choice process into 5 different stages, and suggests heuristics that may be relevant to each(11). The first stage involves determining the possible outcomes of a choice, the probabilities associated with the outcomes, and the confidence that each probability is correct(11). The three categories of availability, representativeness and anchoring are heuristics involved in the first stage.

Availability represents the ease with which a possibility comes to mind. The more available a possibility is, the more likely it seems that it will occur. Thus availability affects a person's perception of how probable various events are. Factors that increase the availability of a possibility are: familiarity, Salience, recentness, effectiveness of search set, and ease of scenario construction(11). Dramatic events are more salient than subtle ones, and therefore seem more likely to occur(11). Because of the way we recall information, some events are easier recalled than others, for example some people recall faces better than names or vice versa(11). Thus the way in which we search for possibilities may affect what we recall. Also, things that can be imagined easier will be more available than things that are difficult to imagine(11).

Representativeness is important when a person is trying to determine whether some event A is caused by an event B(11). The general rule is that, the more A resembles B, the more likely A is to have been caused by B(11). There are 5 classes of errors that humans make when attempting this determination: theoretical errors, insensitivity to prior outcomes, insensitivity to sample size, misperceptions of chance, and misconceptions of regression toward a mean(11). A misunderstanding of the process in question can lead to theoretical errors(11). Also, people tend to rely more on representativeness even when statistical probability of an event is known(11). People also tend to use the law of averages without regard to errors from small sample sizes(11). Similarly, short sequences of events are often assumed to be representative of a process(11). When observing a process that regresses toward a mean, the conflict between regression and representativeness may cause spurious casual explanations for the process(11).

Anchoring is illustrated by the effect that when people start an estimation with any particular initial value, they are not likely to move very far from that value(11). Also related to anchoring is an effect called framing. The way in which information is presented to a person, or framed, affects the person's understanding of the likelihood of possible outcomes(11). In addition, people generally view outcomes that will favor them as more likely than outcomes that won't(11).

A subject's confidence in their opinion about how probable an event is, generally relates positively to how easily they made the probability assignment(11). This effect is independent of the actual probability that they determine(11). A subject's confidence determinations generally err toward being overconfident in their predictions(11). Subjects will often attempt to make predictions regarding processes from which they have little knowledge(11).

In the second stage of the decision process, the subject determines how each of the possible outcomes would affect their objective, like finding the personal value of each possible outcome(11). Then in the third stage, decision weights are assigned to the possible choices from the determinations in stage one(11). The method by which this might be done is to multiply the probability of an event by the evaluated value of that outcome(11). Then each possible outcome has a weighted value. The fourth stage is choice between available options(11). In general, subjects will choose the choice associated with the highest decision weight(11). However, several things may affect the choice stage of the process. First, research shows that most people take risk under conditions of perceived loss, and avoid risk under conditions of perceived gain(11)(3). Second, people tend to overweigh small probabilities, and underweigh large probabilities(11)(9). In addition, when two choices are weighted equally, the choice with the higher confidence level is preferred(11). A fifth and final stage of decision involves the recollection and interpretation of the choice process, especially after the results of the choices are witnessed(11). A bias affecting the process in the fifth stage is the hindsight bias, or the tendency to judge events as more probable in retrospect(11). Additionally affecting the fifth stage is that people tend to look more for reasons why the decisions they made were right rather than wrong, thus providing a skewed understanding of past events(11).

A few of the methods that heuristic judgement theory uses to describe choice behavior are very similar to the methods of economic rationality. Examples are the weighting of various outcomes, and the choice of the outcome with the highest weighted value. However, the guidelines provided by heuristic judgement theory suggest the inclusion of quite a few empirically supported heuristics. In terms of describing human behavior, this theory is much better equipped than economic rationality. The process of weighting, and choosing, still appear as a dubious reflection of the true processes that may occur, but perhaps further work will refine these areas. In addition there is room for the inclusion of further heuristics relevant to a decision process. The guidelines provided by this theory aid in the development of a model of the herding scenario. Not all of the process suggested will be implemented in the model I will develop. Such an ambitious venture awaits a future researcher. However, several parts of the decision process that the herders use in the model will remain compatible with these guidelines. Further descriptions of specific heuristics will additionally further the development of the model.

HEURISTICS

The great number of heuristics that have been documented are all relevant to human decision making. However, I will attempt here to describe in more detail some heuristics that may be important in developing a model of the behavior of two herders on a pasture. Four heuristics that I found relevant are Temporal Discounting, Framing, Social Value Orientation, and Uncertainty.

Temporal Discounting

One heuristic that seems very important to the use of resources is a propensity for the choice of more immediate rewards over a larger, long-term, benefit. This tendency diverges from economic rationality, where the greatest rewards are chosen unconditionally. In common affairs, a person who chooses the more immediate rewards could be said to act impulsively. An important aspect of this tendency is that if both rewards are relatively delayed, then behavior is generally less impulsive, while if one of the rewards occurs immediately or relatively soon then impulsive behavior is more likely(13). For example, a person who is offered one soft drink immediately, or two soft drinks tomorrow will likely opt to take the soft drink being offered now. Conversely, if a person is offered 1 soft drink 20 days from now, or 2 soft drinks 22 days from now then they are more likely to choose the latter. Impulsive behavior is adaptive, because if allowed to diverge from previous plans, a person is likely to decide on the 20th day to have a soft drink, and forfeit the two drinks that they could get on the 22nd day. Thus, without constraints, this behavior is more of a process than a one-time calculation. This temporal bias has been modeled by several authors using the concept of multiple selves(13). Contending that this formulation reflects how we intuitively think about ourselves, a 1998 publication by

Max H Bazerman, Ann E Tenbrunsel, and Kimberly Wade-Benzoni states that the intrapersonal conflict is a difference between what we *want* to do and what we *think* we should do(2). The two selves are characterized as an impulsive self, and a reasoned self(2). Many behaviors where we continue to do things like smoke cigarettes, even when we think we should stop, are explained by the multiple selves model. My impression of the multiple selves models is that they are psychological explanations of how we are impulsive rather than an empirical formula describing behavior. This theory is an interesting explanation, and is compatible with empirical evidence that a bias does exist.

Empirical evidence from experiments show that subjects' choices consistently follow a pattern of discounting that is best modeled with a general hyperbolic function(2)(16). This type of modeling is reminiscent of the economic utility paradigm because benefits are considered measurable or quantifiable, but in this case the value of the benefits are time dependent due to temporal discounting. Including hyperbolic temporal discounting in the utility of each choice offers a way to model the behavior of animals and humans who are faced with choices resulting in temporally distinct rewards. Thus, an alternative utility function that takes temporal concerns into account can be formulated. Just because the behavior can be described in this way does not mean that the temporal discounting and utility considerations reflect actual psychological processes. However, under the condition that the concept of utility with a hyperbolic temporal discounting factor is applied strictly to behavior, this representation offers a way to numerically model the behavior. The more intriguing psychological or physiological processes that may account for this behavior are not covered in this research.

The general hyperbolic function is of the form $(1+\alpha\tau)^{-\lambda/\alpha}$ where $\alpha, \lambda > 0$ are constants and in this case, $\tau > 0$ is the independent variable which represents the number of time periods between the choice and the reward(13)(14). It can be proven that this function is monotonously decreasing by showing that the value of the first derivative is always negative. In addition, it can be proven that the rate of decline is monotonously decreasing by showing that the value of the second derivative is always positive. These features of the function are consistent with the verbal descriptions of this bias that have been given. The value of this function is greatest at $\tau = 0$ and is thereafter steadily declining, which is consistent with weighting imminent rewards more than distant rewards. That the rate of decline is steadily decreasing is consistent with the phenomena that two temporally differentiated rewards in the distant future are relatively less weighted with respect to each other than two temporally differentiated rewards in the near future.

The standard model of discounting in economics is an exponential function because it is a more tractable function(13)(14). More than twelve studies have compared the exponential curve with the hyperbolic curve and they all show that the hyperbolic curve is a better fit(14). Therefore, it seems safe to assume that the hyperbolic curve is a more realistic model of behavior. Further support for the hyperbolic model comes from its explanation in the economics of 'empirical anomalies' such as: "[1] missing precautionary savings effects, [2] incongruence between the elasticity of intertemporal substitution and the inverse of the coefficient of relative risk aversion, [3] consumption discontinuities at retirement, [4] variation in patience over life cycle, [5] consumer self-reports of 'undersaving'," and more(14). Also, an analytically convenient discrete approximation to the general hyperbolic function is the Quasi-Hyperbolic function $\{1, \beta\delta, \beta\delta^2, \beta\delta^3, \ldots\}$ where β and δ are constants(13)(14). The hyperbolic, exponential and quasi-hyperbolic functions are plotted below in a graph(13).

Figure 1. Exponential, Hyperbolic, and Quasi-Hyperbolic Discount Functions[a]

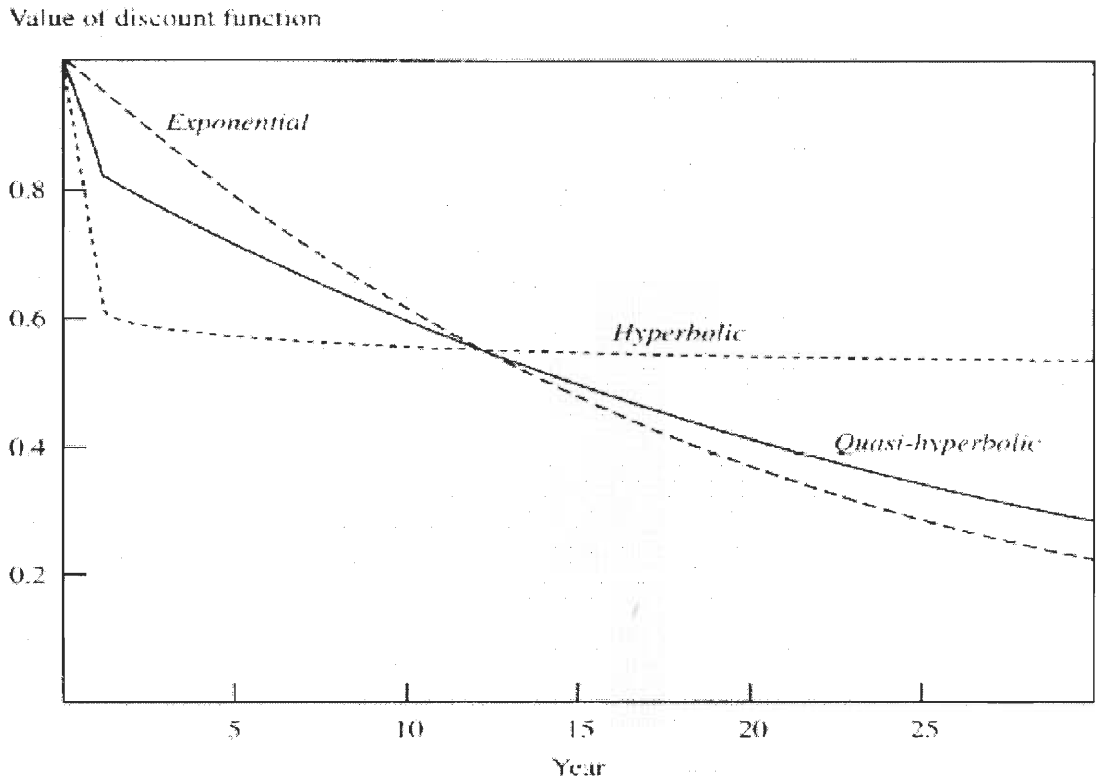


Fig. 2.1

"Figure plots three discount functions: exponential. δ^{τ}, with $\delta = 0.951$, and τ representing the year: hyperbolic: $(1 + \alpha\tau)^{-\lambda/\alpha}$, with $\alpha = 25 \times 10^{4}$ and $\lambda = 10^{4}$: and quasi-hyperbolic: $\{1, \beta\delta, \beta\delta^{2}, \beta\delta^{3}, \ldots\}$, with $\beta = 0.85$ and $\delta = 0.964$." Quoted(13). The above graph is copied from "Self-Control and Saving for Retirement", a 1998 article by David I. Liablson, Andrea Repetto, & Jeremy Tobacman(13).

That an animal's behavior, when faced with intertemporal rewards, can be described by a hyperbolic discounting factor, was first shown by Shin-Ho Chung and Richard Herrnstein(13). The hyperbolic discounting function was later shown to apply to human behavior as well(13). The following hyperbolic equation is a model of temporal discounting which accurately describes behavior in both human and non-human animals(16).

Equation a) $$v_d = \frac{V}{1 + kd}$$

The dependent variable v_d is the value that an immediate reward would have to have so that it would be equivalent to the delayed reward; V is the value that the delayed reward would have if it were an immediate reward; and k is an empirically defined constant representing the degree of impulsivity, or extent of discounting. Behavior can be modeled by applying this equation to temporally distinct rewards and picking the choice that offers the reward with the highest v_d as the most likely for a subject to choose. Of course this assumes that the rewards are measurable or quantifiable to some degree of accuracy. By adjusting k, equation a) can be tailored for different degrees of impulsivity. The higher the k value, the more a delayed reward is discounted in value. In several studies of discounting in alcoholics and drug users, k is shown to correlate with personality measures of impulsiveness(16).

If a method can be substantiated for determining the value of k for a situation using measures of personality, then it is possible that an individual's behavior can be predicted with some accuracy.

I will adopt the notation used by Chris J. Warry, Bob Remington, and Edmund J. S. Sonuga-Barke in their 1999 article "When More Means Less: Factors affection Human Self-Control in a Local versus Global Choice Paradigm"(23). The inter-temporal conflict can be described as a choice between a smaller but less delayed reward (smaller-sooner or SS) and a larger but more delayed reward (Larger-Later or LL)(23).

Laboratory studies of inter-temporal conflict generally take the form of repeated discrete exposures to a choice between SS and LL rewards where the delay to reward is controlled(23). The shape of the discounting function has been studied by finding the indifference points at which a subject is equally prone to choosing either the SS or LL points(16). The points of indifference are found by holding the LL reward constant in time and size, while the size of the SS reward is adjusted until a subject is equally prone to choose either reward(16). By determining a number of these points, the basis for determining a discounting function is established.

Animals generally choose the SS rewards, thus failing to maximize their total reward(23). Many experimental studies have been done on human behavior when SS and LL choices are available(23). Often, the studies with humans offer a verbal description of the SS versus LL choice before a task is given, or rely on a stated preference for the SS or LL choice(23). Whether or not humans always discount the value of LL rewards compared to SS rewards remains a subject of controversy(23). Some studies with adult humans show little or no impulsivity, or large differences in individual behavior(23). Studies with non-human animals are easier to interpret than studies of human choice behavior with regard to this temporal bias(23). Despite criticisms, the general view is that humans, like animals, are prone to act impulsively(23). In addition, there is significant evidence that human behavior cam be modeled using hyperbolic functions(23).

Behavior when faced with a SS versus LL choice situation is influenced by at least three categories of factors(23). The size of the temporal discounting effect is moderated by not only the difference in delay between the two rewards but also other motivational factors such as the difference in size between the two rewards(23). There are indications that smaller rewards are discounted more rapidly than larger rewards(16). Another category of moderators is cognitive factors, such as the saliency of the potential outcomes, which may affect the understanding of the value of the choices(23). Also, social factors such as how another person behaves when faced with the same choices, or the outcomes that they achieve are also important(23). Despite the inclusion of motivational, cognitive, and social factors in a study with human subjects, the overall results showed that a tendency to choose the LL reward remained(Chris J. Warry, Bob Remington, Edmund J. S. Sonuga-Barke, 1999)(23). The same study also indicates that in a repetitive choice situation with a cognitively uncertain reward mechanism, providing limited forecasts of results, or showing how well an "expert" would be doing increases the number of LL choices a subject makes(23). Thus forecast information, or certain social comparison information, may increase a subject's performance. I have been unable to find significant information on how motivational, cognitive, and social factors specifically interact with temporal discounting.

Although there are descriptions of how we take risks in the literature, I have not found theory on how temporal discounting and cognitive uncertainty interact. This is unfortunate, because in the model scenario, it intuitively appears that both delayed reward and cognitive uncertainty regarding the actions of the other herder may play a key role. An additional difficulty with applying hyperbolic discounting to the model scenario is that no empirical studies have been done to assess the k values that might be associated with the herder's decisions.

Framing

The way in which logically identical choices are presented to a subject has been shown to significantly affect choice behavior(6)(3). This effect is often called framing. Prospect Theory, developed by Daniel Kahneman and Amos Tversky, describes the effects of framing(6)(3). What Prospect theory proposes is that choices are affected more by a reference that is neutral in terms of gain or loss than on the final outcome(6)(3). If prospective outcomes are less favorable than the reference outcome then the subject is described as having a loss frame, and views the results in terms of amounts lost(6). Conversely, if prospective outcomes are more favorable than the reference outcome, the subjects have a gain frame and view the results in terms of amounts gained(6). The following illustrates how a problem can be described such as to prompt both loss and gain frames. A subject is given $100 but must roll a dice with a 1/6 chance to lose $80 on the roll. This description is likely to prompt a loss frame because the subject is starting at a reference point of 100 dollars. Another subject is given $20 and must roll a dice for a 5/6 chance to win $80. This subject is likely to have a gain frame because they start with $20 and stand to increase the reward. Both subjects are presented with a logically identical situation, yet the different order of presentation provides distinct reference points. An important tenant of Prospect Theory is a prediction that losses will be weighed more heavily than gains(6). Thus, an asymmetry in behavior is predicted between subjects in a loss frame and subjects in a gain frame. The difference between two options in a loss frame will be exaggerated compared to the difference between two options in a gain frame. The term 'loss aversion' is often used to denote the greater weighting of losses. Research on human decision making generally supports the concept of loss aversion(6). To apply loss aversion to a mathematical model of the model scenario, I will need to assume a reference point that is neutral to the herders in terms of loss and gain. It appears to me that a reasonable reference point would be a moving average of profits over a period of a week or so. This is speculative, but seemingly reasonable. Another possibility is to assume that the reference points of the herders are fixed from the onset, i.e., they expect a preset income from the pasture.

Additionally, in research it is sometimes assumed that losses are weighed twice as heavily as gains, and this is the assumption that I would make in the model development(6).

Social Value Orientation

A categorization of preferences for distribution of rewards to self and other has been made which splits people into the categories of cooperative, individualistic, and competitive(6)(19)(21). Cooperative people are concerned with maximizing joint outcomes, individualistic people are concerned solely with their own outcomes, and competitive people are concerned with maximizing their own outcomes relative to other's outcomes(6)(19)(21). These are categories of social value orientation established by M. Deutsch (1960), and supported by further research(6)(21). A basic assumption behind social value orientation categorization is that different people are predisposed to different choice behavior when faced with an interdependent situation. A person's social value orientation can be measured with tests that generally consist of choices between self-other distributions(6)(19)(21)(17). Empirical research has shown that there are significant correlations between social value orientation and behavior in social dilemmas(21)(17). In addition, significant correlations between social value orientation and perceptual differences have been found in social dilemmas(21). The empirical support for these correlations comes from experiments using iterated games in which a subject is interdependent with another entity over a number of trials(21). The empirical research supports the following behavioral effects: "[a] prosocial subjects are very willing to cooperate, so long as it is reciprocated by the partner, [b] individualists are not willing to cooperate, tend to take advantage of cooperative partners, but do cooperate if there are obvious selfish reasons for doing so", and "[c] competitors are not willing to cooperate regardless of the partner's strategy."(21). In addition to the laboratory studies done, research outside the laboratory has observed that competitors and individualists contribute less volunteer time than cooperators(17). There is also empirical support for perceptual differences between people that has been referred to as the Might vs. Morality effect(21)(22). Relatively, cooperators view others in terms of morality, while individualists and competitors view others in terms of might (strong vs. weak, or intelligent vs. unintelligent)(19)(21). Thus a cooperator may view a person who defects in an interdependent situation as bad or immoral, while the individualist or competitor who defected may view the cooperator as weak or unintelligent for choosing to cooperate(21). Although I have no immediate plans to include perceptual differences in the model, it may be interesting to explore various social value orientations for the herders. For an applicable set of weightings for the different social value orientations, a set used in previous research should suffice. Cooperators are assumed to weigh their own and the other's benefits with a factor of 1.0 each, individualists are assumed to weigh their own benefits with 1.0 and other's benefits with 0, competitors are assumed to weigh their own benefits with 1.0 and other's benefits with -1.0(6). These factors can be used to represent the various social value orientations for the herders in the model.

Uncertainty

In general, experimental research shows that in social dilemmas, increased uncertainty about the size of the resource, or the rate at which a resource is replenished, results in an increase in the amount that is taken from the resource by subjects(19). Research has also shown that subjects expect others to take more of the resource under conditions of high uncertainty(19). This behavior is consistent with another reported bias. People tend toward unfounded optimism regarding hoped for outcomes(11). An assumption that people may hope for the higher estimate of the resource would imply that trend of behavior in social dilemmas may be related to the optimism bias. Thus I will assume that under conditions of uncertainty the herders may choose to believe the more favorable estimates.

Expectations

Research suggests several effects that could occur on the pasture. Although results from experiments may not always be generalized, they provide some of the few suggestions available. Several causal relations of interest involve the discussed heuristics, which are social value orientation, temporal discounting, framing, and uncertainty. In general, competitors take far more resources from a common pool than cooperators(19). A 1991 study by Mannix lends support to the notion that high temporal discount rates facilitate the over-consumption of resources, while low temporal discount rates help maintain or increase the resource pool(19). Also, as the level of uncertainty about the size of a resource or the replenishment rate increases, generally the consumption of the resource by subjects increases as well(19).

There is also a causal relation of interest that involves a combination of factors. Laboratory research with human subjects shows that there is an interaction between social value orientation, and whether an individual is in a gain or loss frame(6). Cooperators cooperated more in a loss frame than in a gain frame, individualists cooperated less in a loss frame than in a gain frame, while no significant interaction was shown to exist between competitors and frame(6).

Modeling the Pasture

A model of the behavior of the herders on the pasture will be developed in two stages. The first stage is the development of the relations between the cows and the pasture. Following the first stage, the second stage is the development of decision-making methods that the model herders use to control the number of cattle that they graze on the pasture. Following the development of the model, there will be a discussion of the dynamics that the model exhibits.

The Cattle and the Pasture

The development of the first stage of the model involves the reduction of the model scenario by stating assumptions about the physical situation. The model scenario needs to be condensed to a number of variables, and any constraints on the variables, as well as specified relations between the variables. A mathematical model will be built by these methods and a modeling technique called system dynamics. A brief description of important concepts used to describe the mechanics of the pasture will be followed by an explanation of the systems dynamics method of modeling, and the first stage of modeling.

The two main elements to the model in the first stage are the cattle and the pasture. Assuming that there is a quantifiable amount of grass on the pasture, grass becomes a variable quantity. Similarly, considering that there are a quantifiable number of cows in each of the herds, the number of cattle becomes a variable quantity. Seemingly self-evident constraints on the mentioned variables are that they should not become negative. Negative quantities of grass do not make sense, and neither do negative quantities of cattle. In describing the physical existence of grass, it is important to note that grass grows. This growth rate may be dependent on the relative amount of grass currently present. For example, grass that is gnawed down to the roots will take a very long time to grow back if ever, while at healthier lengths grass will grow quickly. In addition, as grass gets much longer, the growth rate slows down again, perhaps slowed by a growth boundary, and the death of old grass. Thus I will assume that grass grows according to a growth rate that is dependent upon the length of the grass, and is shaped somewhat like a bell curve. I assume that the cattle are not dairy cattle, but are sold on the market as soon as they mature. Thus, the average time to maturity becomes a factor to include in the model. Not only do cattle mature, but in the process they must eat grass from the pasture to survive. Thus, cattle must consume grass, and I assume that the amount of grass that a herd consumes in a day is directly proportional to the number of cattle in the herd. Additionally, as grass becomes shorter cattle may have more difficulty grazing, and thus I will design the model so that when there is a shortage of grass, cattle will have increasing difficulty obtaining the remaining grass from the pasture. Furthermore, because the weight of cattle may affect the market price, I assume that the amount of grass eaten by cattle will affect their weight, and that low weight cattle are sold for disproportionately less. This assumption may become important when developing decision models for the herders. A simplifying assumption that the model makes is that the market price of healthy cattle is constant. Because of the number of assumptions in the model is extensive, any further assumptions will be introduced with the model development.

System Dynamics

System dynamics is a method by which approximate solutions to differential equations can be constructed. The key distinction between system dynamics and other mathematical modeling techniques is the use of the graphical interface to represent the variables and rates of the differential equations. The development of a system dynamics model is essentially the development of a series of first order differential equations, which are then solved computationally. The series of first order differential equations are allowed to be linked, and thus allow the reduction of models to a single higher order differential equation. Methods such as Euler's method and Runge-Kutta are used iteratively, in a standard computational procedure to find solutions.

The STELLA modeling program is a system dynamics tool for building graphical representations of models, and is designed to allow mathematical relations to be defined both graphically and logically. Once a model is completely defined, STELLA allows the model to be "run", and the behavior of the system over time can be viewed. To "run" the model means to find the time dependent solution to the system using computational methods.

The basic building blocks of system dynamics models are *stocks*, *flows* and *converters*. The properties of a system that can be quantified, in terms of the number of units that exist at a particular time, are called *stocks*. Stocks relate to countable things that may accumulate and deplete. Mathematicians would call such properties *variables* rather than stocks. On the other hand, flows refer to the rates at which stocks are changing. In mathematical terms, flows are equivalent to *derivatives*. Relative to stocks, flows are measurable in units/time. In addition to stocks and flows, systems dynamics utilizes what I will refer to as *converters*. Converters are values that are neither stocks nor flows. They can be constants, or they can be the value of some equation. The primary significance of converters in system dynamics is to provide a reference for equations and constants that need to be used more than once or should be explicitly identified. In addition, *connectors* are used to show the dependence of one value upon another. The graphical representations of stocks, flows, converters, and connectors that will be used are shown below.

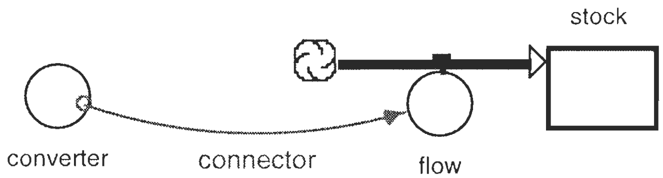


fig. 3.1

The connector shows that **flow** must utilize the value of **converter**. Each type of object is represented uniquely in this graphical way. This figure is representative of a basic building block of a system dynamics model. The system dynamics software STELLA was used to create this image, and will be used for the development of the model.

There is some graphical significance to the way that stocks and flows are represented. The stock is represented as a box because boxes can contain a quantity of something. The double arrowed tubes, which connect to the stock, are appropriate because they represent channels by which the quantities can flow into and out of the box. The flows, which are connected to the tubes, can be viewed as pumps, which are pushing quantities into the box, and sucking quantities out of the box through the tubes. The rate at which the pumps move quantities from and into the box can be variable, thus allowing a dynamic system. And finally the squiggly looking things at the end of the tubes represent clouds. When the flow pumps from somewhere into the stock, that somewhere, is represented by a cloud. The cloud symbolizes the end of the limited universe recognized by the model. It is important to examine these clouds, as they represent a certain aspect of the assumed boundaries for the system being described.

There are some rules that stocks and flows are constrained to, by system dynamics convention. Flows are always connected to a stock and a stock always has at least one flow. In this way neither flows nor stocks exist independently of each other. Any stock that is an unchanging quantity can simply be represented as a converter, and is thus not considered a stock. In a similar way flows that are not connected to a stock are not used because flows refer strictly to the rate of change of a stock.

Modeling the Pasture and Cattle

On the pasture, it would be appropriate to consider the grass a stock, because there would be a theoretically quantifiable amount of grass on the pasture. The amount of grass existing on the pasture will be described by a stock which I will call **Grass**. The value of **Grass** can change over time depending on the how fast the grass grows, and how much grass the grazing herd consumes. The rate at which the grass grows is a flow, and will be assigned the name **growth**. The amount of grass that the herd consumes is also a flow, and will be called **consumption**. **Growth** and

consumption are the two flows that I will assume to control the **Grass** stock. From this description of the pasture, a preliminary relation has been defined:

Grass = (*Initial Value*) + **growth** - **consumption**

This equation defines how the amount of grass on the pasture will change when starting with a known amount of grass with a value of *Initial Value*. The relation can be represented graphically, by the following systems dynamics diagram.

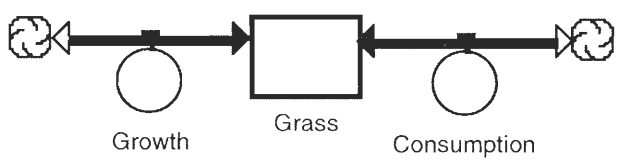


fig 3.2

The *Initial Value* is specified in the **Grass** stock and is not part of the graphical representation.

The natural progression would be to ask how to go about defining **Growth** and **Consumption**, and this is what I plan to address next. I assume that each animal eats a set amount of grass every day when grass is plentiful. I can arrange the units of grass without any logical change in relations, so that each animal optimally consumes 1 unit of grass per day. The total herd size will be the combination of both herds of the two herders. The two herds are best represented as individual stocks in order to allow greater definition when defining decision mechanisms. Thus, the converter **Total Cattle** will be introduced to hold the value of the total number of cattle. Under conditions when grass is plentiful, **Consumption** would equal **Total Cattle**. However, since I am not assuming that grass would always be plentiful, I will introduce the converter **Availability** to represent the fraction of the optimal amount of grass that each cow is getting. Using these definitions and assumptions leads to a relation describing the total amount of grass consumed per day.

Consumption = **Total Cattle * Availability**

Consumption is defined in terms of units grass per day. **Availability** is made a function of the grass ratio. When the **Grass Ratio** is over 0.33 in value, **Availability** has a value of 1.00, assuming that the cattle eat the optimal amount of grass. When the **Grass Ratio** is below 0.33 the **Availability** declines gradually before plummeting to 0, representing the increasing difficulty obtaining the grass when it is shorter. Now that **Consumption** is defined, the other flow **Growth** needs to be defined.

How can the growth process of grass be described? The behavior of grass has several constraints. As grass is eaten farther down to the roots, I assume that the rate at which it recovers is slower and slower. When the grass is above a certain height above the roots, I assume that the growth rate is fairly constant except when the grass gets very tall. A plot of very tall grass must grow at a slowed rate, because otherwise, there would be no end to the amount of biomass that a plot of grass can achieve. Note that this latter slowed growth rate could be the result of the death of grass after it reaches maturity, however a slowed growth rate can be taken as an equivalent indicator of biomass accumulation. My first assumption in creating a mathematical description of the growth is that **Growth** is a fraction of the amount of grass currently on the pasture. Thus **Growth** is considered to be a fraction of **Grass** per day. I will also assume that there is a theoretical limit to the amount of grass that can grow on the pasture, and will call this converter **Grass Cap**. Then I have a way to define the relative amount of grass on the pasture as the converter **Grass Ratio**:

Grass Ratio = Grass / Grass Cap

I will assume somewhat arbitrarily that the **Grass Cap** has a value of 5000. The **Grass Cap** is another measure of the size of the pasture. Having **Grass Ratio** defined, I can now create a growth fraction that is dependent on the relative amount of grass on the pasture. The following graph shows the converter **Growth Frac** as a function of **Grass Ratio** percent.

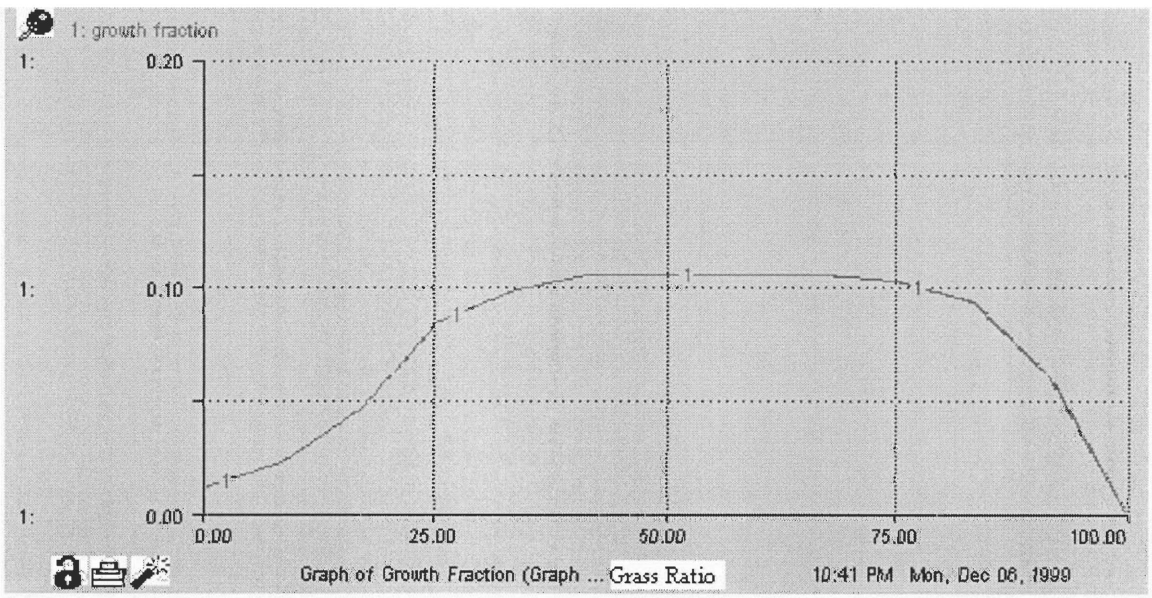


Fig. 3.3

For most values that **Grass Ratio** achieves the **Growth Frac** will be around 0.1 in value. Consistent with the assumptions made, the follow relation will describe how much grass is growing:

Growth = (Grass + 1) * Growth Frac

The addition of 1 to **Grass** in the growth definition is to provide a seed to start the growth process in case there is no grass on the pasture. Thus the flows into and out of the **Grass** stock have been defined.

Not all of the relations described have been fully defined. I will assume that the initial value of **Grass** will be **Grass Cap/2**. This value for Grass starts the model out with the pasture at half of the full grass capacity. The following diagram shows the current development of the model.

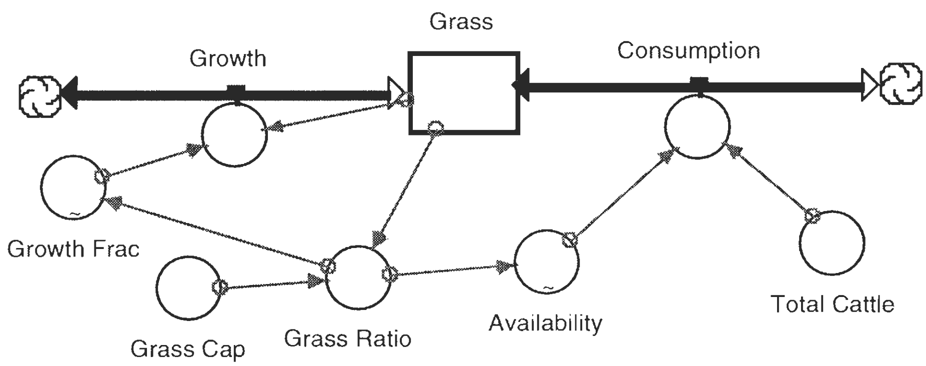


Fig. 3.4

This diagram shows all of the elements and dependencies explained so far. In addition, the following are the mathematical relations defined so far in the model:

Grass on Pasture

Grass(19) = Grass(t - dt) + (Growth - Consumption) * dt

INIT Grass = Grass_Cap/2

INFLOWS:

```
Growth = (Grass+1)*Growth_Frac
OUTFLOWS:
Consumption = Total_Cattle*Availability


Grass_Cap = 5000
Grass_Ratio = Grass/Grass_Cap
Availability = GRAPH(Grass_Ratio)
(0.00, 0.00), (0.03, 0.33), (0.06, 0.565), (0.09, 0.695),
(0.12, 0.78), (0.15, 0.85), (0.18, 0.9), (0.21, 0.945),
(0.24, 0.975), (0.27, 0.99), (0.3, 1.00)
Growth_Frac = GRAPH(Grass_Ratio)
(0.00, 0.011), (0.0833, 0.022), (0.167, 0.045), (0.25,
0.084), (0.333, 0.098), (0.417, 0.105), (0.5, 0.105),
(0.583, 0.105), (0.667, 0.105), (0.75, 0.102), (0.833,
0.093), (0.917, 0.06), (1.00, 0.00)
```

If you are familiar with differential equations you may recognize the equation for the **Grass** stock is a differential function where **t** is the time and **dt** is, by convention, an infinitely small time increment. In this case **dt** actually describes a small but finite time increment, and the equation describes how to linearly extrapolate from **Grass**(**t**-**dt**) to find **Grass**(19). Thus the numerical solution to the differential equation { d/dt **Grass** = **growth** - **consumption** } is being sought by linear extrapolation from the initial value of **Grass**, which is labeled **INIT Grass**. This numerical solution is what is presented when the model is run, showing the behavior of **Grass**(19). This numerical method is commonly known as Euler's method. Other, non-linear, methods such as Runga-Kutta are also available in STELLA.

It is common technique to design a model to start in equilibrium, and then change parameters to see the results. Further in the model, the converter **Total Cattle** will be shown to have the initial value of **Growth**. This will ensure that the model starts with **Growth** and **Consumption** being equal, and thus **Grass** would remain constant in value so long as **Total Cattle** remains at its initial value. The section in the model defining Grass is influenced in one spot by the rest of the model. The **Grass** sector has influence from the rest of the model only from the **Total Cattle** converter. The assumption is that only the existence of cattle can decrease the amount of grass from the pasture. The model does not acknowledge that other animals may eat the grass, or that grass may have a death rate. In addition, the model does not assume that the cattle influence the pasture in ways other than consumption of the grass.

Cattle dynamics

The two herds will be treated as separate stocks with each herd owned by one of the herders. An arrayed stock, **Herds**, will hold the quantities of cattle that the two herders own. Arrayed objects can be stocks, flows, and converters, which represent more than a single instance of the object, but are represented by a single graphical figure. Arrays are used when distinct numeric instances of a logically identical structure are needed. Thus, the arrayed **Herds** stock is used to represent two distinct stocks, each one belonging to one of the two herders. Arrayed objects are represented graphically by a triple image as illustrated below.

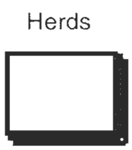


Fig. 3.5

The **Cattle** stocks will be moderated by the two flows **Adjustment**, and **Discharge**. The cattle sector is influenced in only one spot by the decisions of the herders. The herders affect the cattle sector by the decisions of the herders to add or remove sheep through the flow **Adjustment**. It is assumed that the herders do not control the number of cattle sold, but that a constant fraction of the cattle are sold off every day. Another assumption made is that a fraction of the cattle die every day, and that this fraction increases as the average weight of cattle decreases. The **Discharge** flow removes cattle that are sold or that die from the **Cattle** stock. Cattle are not treated discretely, so it is possible to sell or acquire a fraction of a unit of cattle. This assumption can be justified by the assertion that a unit of cattle is not necessarily a single cow, but can be a large number of cattle instead. Shown below is the cattle sector of the model:

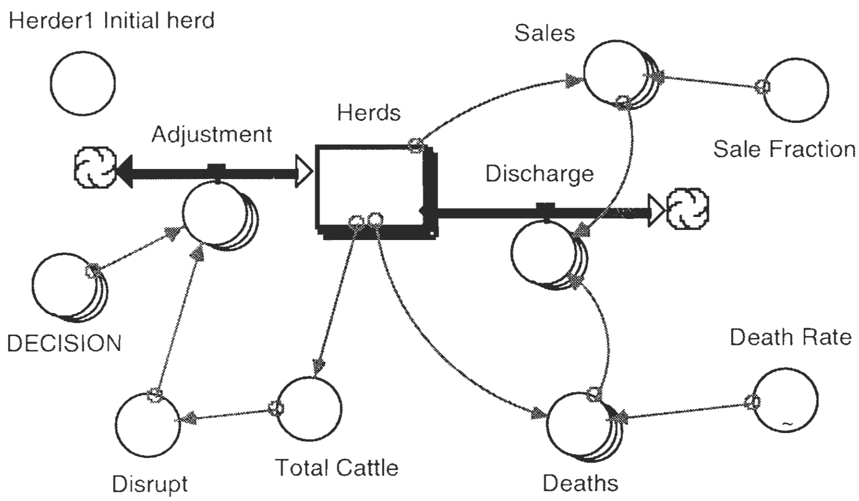


Fig. 3.6

Several parts of this section are arrayed, to account for the two different herders, with their individual herds and decisions. The **DECISION** converter holds the values of the decisions of the two herders. The **Disrupt** converter is used to disequilibriate the model for testing, and is not otherwise significant. The lone converter **Herder1 Initial herd** holds the fraction of the total herd that the first herder starts out with. For most purposes, I assume that the herd is split evenly, so **Herder1 Initial herd** has a value of ½. Below are the equations associated with the cattle sector:

```
Cattle
Herds[1](19) = Herds[1](t - dt) + (Adjustment[1] -
Discharge[1]) * dt
INIT Herds[1] = Growth*Herder1_Initial_herd
Herds[2](19) = Herds[2](t - dt) + (Adjustment[2] -
Discharge[2]) * dt
INIT Herds[2] = Growth*(1-Herder1_Initial_herd)

INFLOWS:
Adjustment[1] = Decision[1] + Disrupt
Adjustment[2] = Decision[2] + Disrupt
OUTFLOWS:
Discharge[1] = Sales[1] + Deaths[1]
Discharge[2] = Sales[2] + Deaths[2]

Deaths[1] = Herds[1]*Death_Rate/10000
Deaths[2] = Herds[2]*Death_Rate/10000
Disrupt = PULSE(Total_Cattle/100,10, 0)*DT*0
Herder1_Initial_herd = 1/2
Sales[1] = Herds[1]*Sale_Fraction
Sales[2] = Herds[2]*Sale_Fraction
Sale_Fraction = 1/600
```

Total_Cattle = Herds[1]+Herds[2]

Notice that the arrayed objects each have two definitions, one for herder #1 and one for herder #2. The **Adjustment** flows are simply the respective **Decisions** of the two herders. The **Discharge** flows are the sum of the respective sales and deaths for the two herders. I assume that the number of deaths each herd has, is the size of the herd times the death rate per 10000. Similarly, the number of sales is the herd size times the **Sale Fraction**. I assume that 1 out of every 600 cattle are sold every day. The initial values of **Herds** are designed so that **Total Cattle** is equal to **Growth**. This will ensure that the model starts in equilibrium so long as the **Availability** is equal to 1. To the current point of development the loose ends are **DECISION** and **Death Rate**. **DECISION** will be left as the last development of the model, and the sector on the weight of the cattle will be developed next.

Weight dynamics

I assume that the death rate is dependent on the weight of the cattle. My model does not take into account deaths due to disease, or malnutrition. Instead, I assume that the weight of the cattle is a sufficient predictor of the death rate. In this sector, I will develop a model of the changeable average weight of the cattle that is dependent on the **Availability** of grass. Below is the structure and equations describing the Weight section.

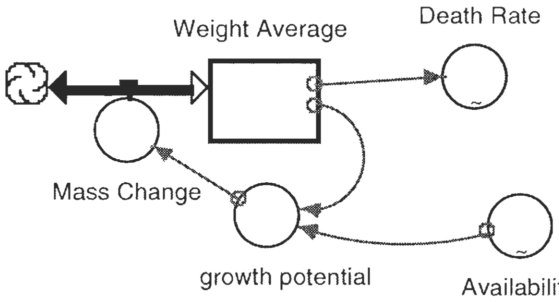


Fig. 3.7

Sheep Weight

Weight_Average(19) = Weight_Average(t - dt) + (Mass_Change) * dt

INIT Weight_Average = Availability

INFLOWS:

Mass_Change = growth_potential/40

growth_potential = Availability-Weight_Average

Death_Rate = GRAPH(Weight_Average)

(0.00, 10000), (0.1, 9900), (0.2, 9550), (0.3, 8250), (0.4, 6100), (0.5, 3600), (0.6, 900), (0.7, 150), (0.8, 50.0), (0.9, 10.0), (1, 5.00)

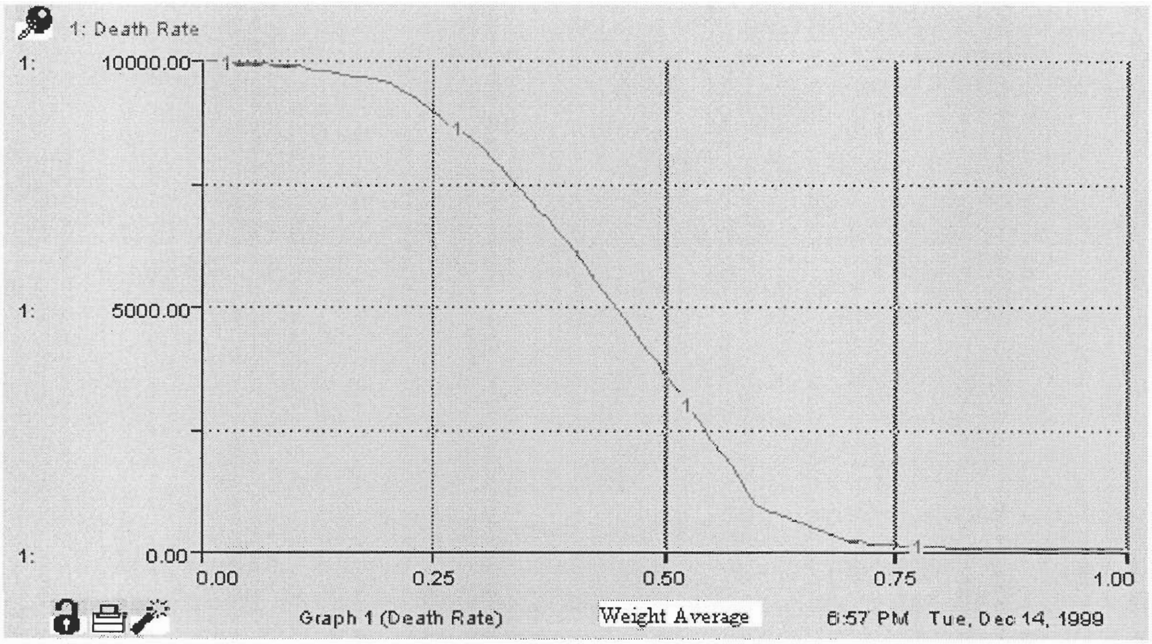


Fig. 3.8

The **Death Rate** is a function of the **Weight Average**, and is scaled as cattle per 10000. By dividing the **Death Rate** by 10000, you get the fraction of cattle that will die that day. When the **Weight Average** is higher than 0.75, the death rate is low, but rapidly increases when the **Weight Average** drops below 0.75 in value. By the time the Weight Average reaches ¼ in value, nearly all the cattle will die in a single day.

The initial value of the **Weight Average** is set to the **Availability**, which is consistent with the assumption that the model starts out in equilibrium. The **Weight Average** is moderated by the flow **Mass Change**, which in turn is moderated by the **Growth Potential**. The **Growth Potential** is simply the difference between the **Availability**, and the **Weight Average**. Holding **Availability** constant, this sector is designed so that the **Weight Average** must adjust to eventually equal the **Availability**. This assumption is based on the intuition the cows cannot become heavier than the available food allows them to, and conversely, underfed cows may become heavier if their diet is increased. An unsubstantiated part of this assumption, is that holding the amount of food cattle get as constant, the asymptotic solution for **Average Weight** will correspond linearly to the amount of food that cattle are getting. It is more likely that a non-linear relation may hold. However, this linear approximation should suffice to produce a rough replica of the pasture.

Much like it sounds, the **Growth Potential** is the amount that the cattle would change in weight if the **Availability** held constant. Since it doesn't make sense that the cattle would change by the **Growth Potential** in one day, I instead assume that the cattle change by 1/40 of the **Growth Potential** every day. Thus if the **Availability** of food for the cattle changes, the **Weight Average** will lag behind and change slowly to adjust to the new diet. The main component of the first stage of modeling have been completed, but before I develop a section on the decision process, I will make a section to keep track of the profits that the herders make.

For simplicity, I assume that a single healthy cow is worth one unit of currency. This is simply a manipulation of the units, and does not reflect any logical assumption. I also assume that the value of an underweight cow is directly proportional to the **Weight Average** squared. This assumption provides a disproportionately low value for underweight cattle. In addition, I assume that it costs 0.1 of a mature cattle's sale value to add an animal to the herd. Below is shown the structure and equations of the profit sector:

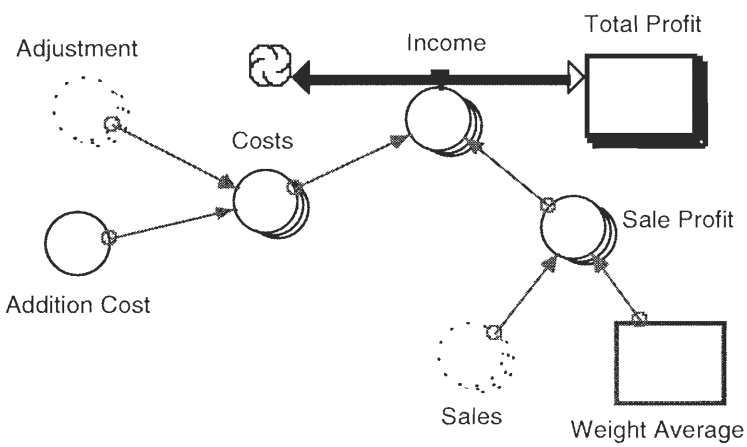


Fig. 3.9

Profits

Total_Profit[Herders](19) = Total_Profit[Herders](t - dt) + (Income[Herders]) * dt

INIT Total_Profit[Herders] = 0

INFLOWS:

Income[1] = Sale_Profit[1] - Costs[1]

```
Income[2] = Sale_Profit[2] - Costs[2]

Addition_Cost = 0.1
Costs[1] = IF Adjustment[1]>0 THEN
Adjustment[1]*Addition_Cost ELSE 0
Costs[2] = IF Adjustment[2]>0 THEN
Adjustment[2]*Addition_Cost ELSE 0
Sale_Profit[1] = Sales[1]*Weight_Average*Weight_Average
Sale_Profit[2] = Sales[2]*Weight_Average*Weight_Average
```

The **Total Profit** is initialized to assuming that the herders have no initial profit. The herder's **Income** is their profits minus their costs. For the **Costs**, Boolean logic is used to ensure that the removed cattle do not have any effect on profit. This concludes the first stage of development. The next step will be the development of the decision mechanisms.

Decision

The Decision process I develop is an intricate system of checks and balances. The initial stage of this development is the construction of sectors that provide information on the state of the pasture. I will create a section that defines the surplus or deficit of grass on the pasture.

The primary quantity that determines how many cattle can be sustained on the pasture is the **Growth** that is occurring on the pasture.

State of the Pasture

The **Growth** on the pasture can be in one of two states. **Growth** is a non-unique function along the 0 to 1 interval of the **Grass Ratio**. There is a single maximum of **Growth** that occurs at a non-extreme value of **Grass Ratio**. A specific value of **Growth** can be past peak or before peak depending on the value of the **Grass Ratio**. This distinction is important when defining the state of the pasture. For example, if **Growth** is before peak then I define the **Undergrowth** as the **Growth** minus **Total Cattle**. **Undergrowth** provides a measure of how far from sustainability the pasture is. If **Undergrowth** is positive, then an **Undergrowth** quantity of cattle can be added to the pasture without causing a collapse of the grass population. Conversely, if **Undergrowth** is negative, then that many cattle would have to be removed from the **Herds** to stabilize the pasture.

When **Growth** is past peak the situation is different. In this case, the **Growth** would decrease as the **Grass Ratio** increases. Thus adding more cattle to the pasture would increase the **Growth** so long as the **Total Cattle** does not exceed the maximum **Growth**. In order to account for this difference, I create a section to capture the value of the maximum **Growth** and the associated value of the **Grass Ratio**. When the Growth reaches the maximum **Growth** value for the first time, the stock **Max Growth** is assigned the value of **Growth**, and **Grass Ratio Max** is assigned the value of the **Grass Ratio** at that point. These stocks provide information on whether the pasture is overgrown or undergrown. When the pasture is overgrown, I assume that the quantity of interest is the difference between the **Max Growth** and the current **Growth**. Thus, when the pasture is overgrown, **Overgrowth** takes on a value of **Max Growth** minus **Growth**. Unlike **Undergrowth**, **Overgrowth** is never negative in value.

The assumption of the existence of the two stocks **Max Growth** and **Grass Ratio Max** implies that the herders notice when the **Growth** has peaked and remember number of cattle that the pasture can sustain at that point. If I assume that the herders do not let the pasture become very overgrown, then this assumption may be less important. However, in deciding whether to add or remove cattle from the pasture, the recognition of the turning point to the overgrown state is an important observation. Below is shown the structure and equations defining the surplus determination sector:

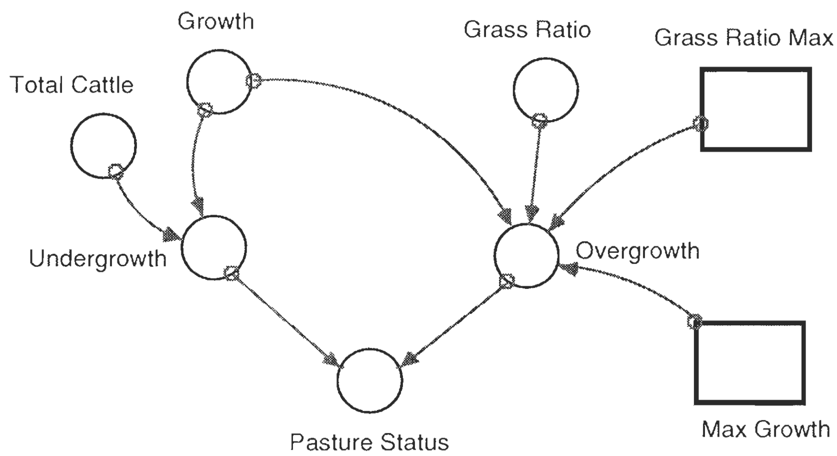


Fig. 3.10

Surplus Determination

Overgrowth = IF Grass_Ratio_Max THEN

(IF Grass_Ratio>Grass_Ratio_Max THEN Max_Growth-Growth

ELSE 0) ELSE 0

Pasture_Status = IF Overgrowth THEN Overgrowth ELSE

Undergrowth

Undergrowth = Growth-Total_Cattle

The **Pasture Status** is a determination of the surplus or deficit on the pasture. The **Overgrowth** surplus is given a priority, and if there is no overgrowth then the value of the **Undergrowth** determination is used.

The values of **Max Growth** and **Grass Ratio Max** are determined from the first moment in the simulation that the **Grass** is increasing while the **Growth** is decreasing. Below is the structure, and equations, which capture these values:

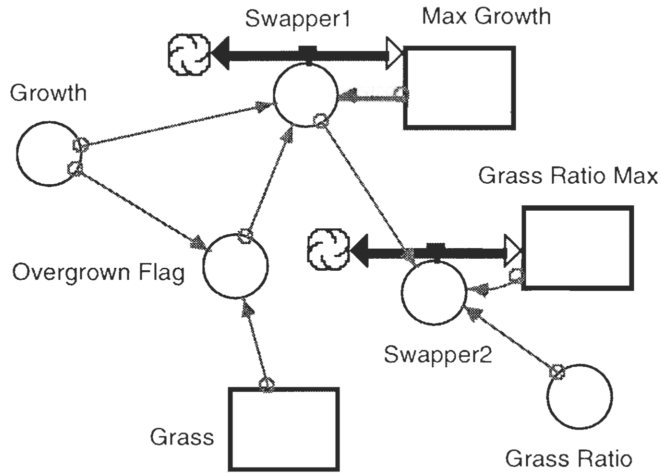


Fig. 3.11

Overgrowth Checker

```
Grass_Ratio_Max(19) = Grass_Ratio_Max(t - dt) + (Swapper2)
* dt
INIT Grass_Ratio_Max = 0
INFLOWS:
Swapper2 = IF Swapper1 THEN PULSE(Grass_Ratio -
Grass_Ratio_Max,TIME,0) ELSE 0


Max_Growth(19) = Max_Growth(t - dt) + (Swapper1) * dt
INIT Max_Growth = 0
INFLOWS:
Swapper1 = IF Overgrown_Flag THEN (
IF Growth>Max_Growth THEN PULSE(Growth-Max_Growth,TIME,0)
ELSE 0) ELSE 0


Overgrown_Flag = IF (DERIVN(Grass,1)>0) AND
(DERIVN(Growth,1)<0) THEN 1 ELSE 0
```

The **Overgrown Flag** can only be true when the **Growth** is past peak. It tests to see whether the first order derivative of **Grass** is positive, while the first order derivative of **Growth** is negative. However it will not always be true when **Growth** is past peak, and is therefore not a reliable indicator. Unfortunately, testing the derivatives of **Growth** and **Grass** cannot give an indication of overgrowth if the system is in equilibrium. Therefore, the stocks, which hold the maximal values, are necessary. When the **Overgrown Flag** is true for the first time, the peak of **Growth** has been reached and the two stocks are filled with the current values at that time. After that point the stocks remain unchanging.

Modeling Decision

The decision sector is a model of herders that includes Social Value Orientation (SVO), uncertainty, and a form of temporal discounting. I break up the **DECISION** that the herders make into the sum of three different components. One component is the number of cattle that are being discharged from the **Herds** stock. This component will be called **Replacements**, and is included so that the **Herds** stock will remain constant in the absence of any other influence from the herders. The second component is a form of investment in the pasture. A converter called **Stimulate** holds a constant that is added to **DECISION**. **Stimulate** is generally assumed to be negative, representing a decrease in the amount of cattle that are added, and an investment in the growth rate. Generally, the discount factor for rewards is assumed to be hyperbolic(2)(16). However, including a hyperbolic discounting function to model the weighting of delayed rewards is difficult in this case, and beyond the sophistication of the current model. The reward that a herder gets from an invested decrease in the amount of cattle that they add to the herd is undefined in value. The actions of both herders will affect the return on the investment. The cumulative result, returned over a period of time, is affected by many variables. For these reasons, I chose a constant investment. By decreasing the value of **Stimulate**, the degree of temporal discounting is reduced. Likewise, a higher value of **Stimulate** corresponds to an increased temporal discounting. The remaining component that is added to **DECISION** is called **Share**. I call it **Share**, because it represents a social dilemma choice that is dependent on the state of the pasture. **Share** contains concepts of social value orientation, and uncertainty. Below is shown the structure and equations of decision sector:

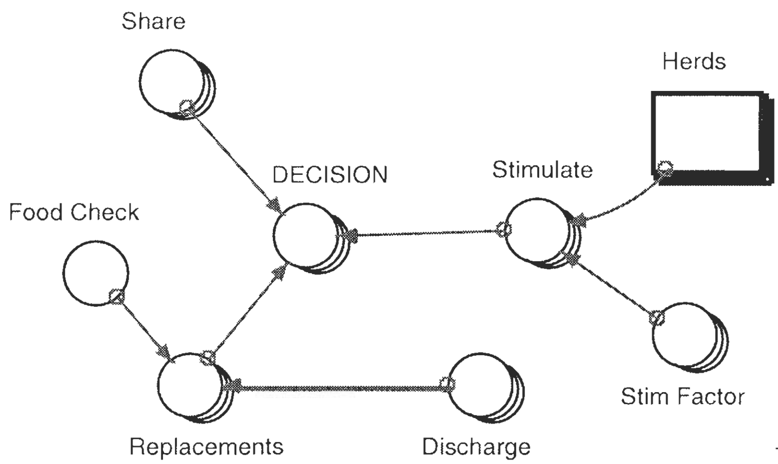


Fig. 3.12

Decision Sector

DECISION[1] = Share[1] + Replacements[1] + Stimulate[1]

DECISION[2] = Share[2] + Replacements[2] + Stimulate[2]

Replacements[1] = Discharge[1]*Food_Check

Replacements[2] = Discharge[2]*Food_Check

Stimulate[1] = IF Herds[1]>1 THEN Stim_Factor[1] ELSE 0

Stimulate[2] = IF Herds[2]>1 THEN Stim_Factor[2] ELSE 0

Stim_Factor[Herders] = -1

This structure is arrayed to account for the two herders. **Stimulate** and **Replacements** are moderated by other factors to account for exceptions. **Replacements** is equal to the **Discharge** except when there is not enough food for each cattle to get a full share. This condition helps keep the model realistic, by ensuring cattle do not continue to be replaced when they are starving, and keeps the **Grass** stock from going negative due to continuous replacement of cattle. **Food Check** is then equal to 0 when availability is less than 1, but this converter is defined further in the model. **Stimulate** is moderated by a Boolean logic statement that ensures that a herder cannot remove more cattle from the pasture than already exist in their herd. The conditions on stimulate prevent having the **Herds** stock become negative due to the effects of **Stimulate**. The **Stim Factor** holds the constant stimulation that will be added to the **DECISION** when appropriate. The **Share** that each herder decides to add independent of the **Stimulate** investment will be discussed next.

Shares of Resources

The resource dependent **Share** that is added to the pasture is derived from two sources. One source is the **Pasture Status**, which is a measure of the distance to sustainability that the pasture is currently at. The second source is a **Greed Share**, which is a positive addition that is independent of the state of the **Growth**. The **Greed Share**, is a mechanism that allows additions at times when there is no surplus or deficit on the pasture. This is important, because otherwise the decisions of the herders would be limited to taking shares of the surplus or deficit. Below is shown the structure and equations that the define the **Share**:

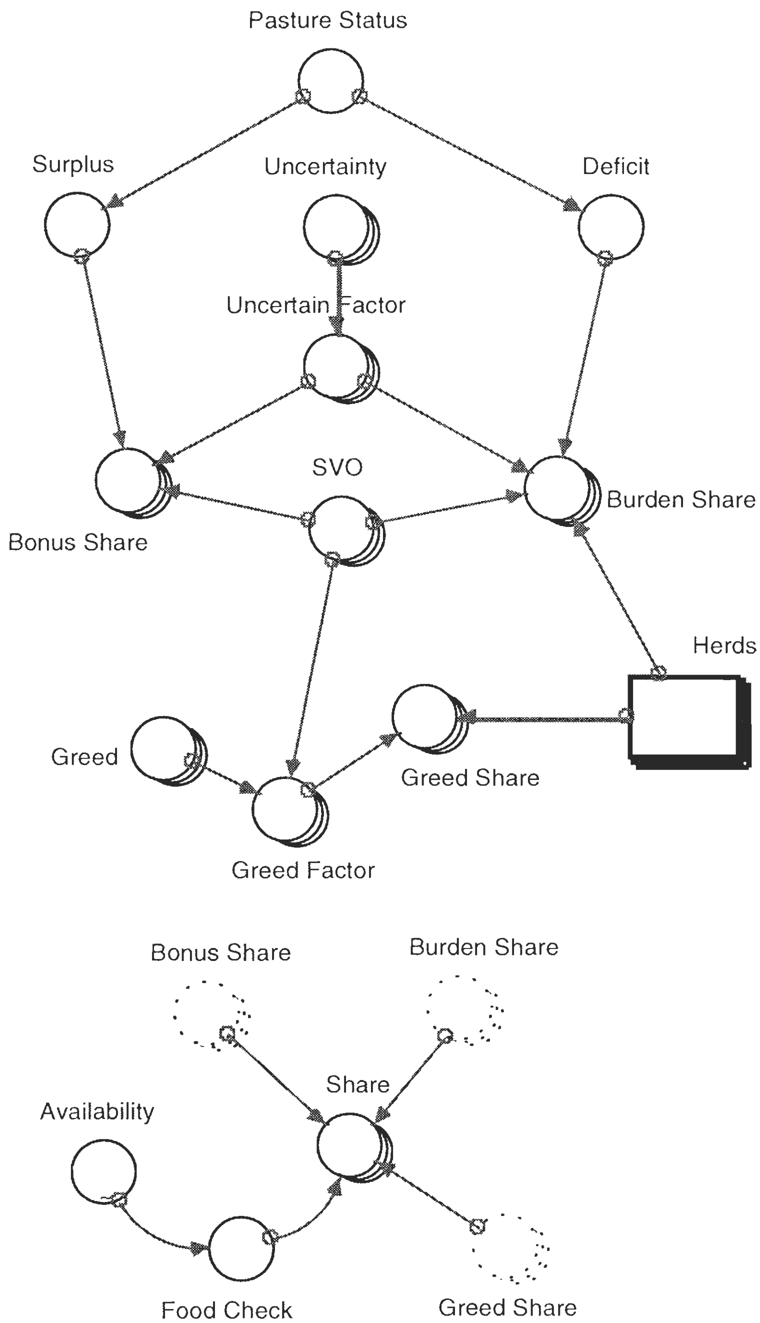


Fig. 3.13

Share

```
Food_Check = IF Availability<1 THEN 0 ELSE 1

Share[1] =  Burden_Share[1] + Food_Check*(Bonus_Share[1] +
Greed_Share[1])

Share[2] =  Burden_Share[2] + Food_Check*(Bonus_Share[2] +
Greed_Share[2])
```

```
Bonus_Share[1] = (1-SVO[1]/2)*Surplus*Uncertain_Factor[1,1]

Bonus_Share[2] = (1-SVO[2]/2)*Surplus*Uncertain_Factor[2,1]

Burden_Share[1] = IF SVO[1]>0 THEN (IF Herds[1]>-SVO[1]/2*Deficit
THEN SVO[1]/2*Deficit*Uncertain_Factor[1,2] ELSE 0) ELSE 0

Burden_Share[2] = IF SVO[2]>0 THEN (IF Herds[2]>-SVO[2]/2*Deficit
THEN SVO[2]/2*Deficit*Uncertain_Factor[2,2] ELSE 0) ELSE 0

Deficit = IF Pasture_Status<0 THEN Pasture_Status ELSE 0

Greed[Herders] = 0.02

Greed_Factor[1] = IF SVO[1]=0 THEN Greed[1] ELSE (IF SVO[1]=-1
THEN Greed[1]*2 ELSE 0)

Greed_Factor[2] = IF SVO[2]=0 THEN Greed[2] ELSE (IF SVO[2]=-1
THEN Greed[2]*2 ELSE 0)

Greed_Share[1] = Herds[2]*Greed_Factor[1]

Greed_Share[2] = Herds[1]*Greed_Factor[2]

Surplus = IF Pasture_Status>0 THEN Pasture_Status ELSE 0

SVO[1] = 1

SVO[2] = 1

Uncertainty[Herders] = 0.05

Uncertain_Factor[1,1] = 1+Uncertainty[1]

Uncertain_Factor[1,2] = 1-Uncertainty[1]

Uncertain_Factor[2,1] = 1+Uncertainty[2]

Uncertain_Factor[2,2] = 1-Uncertainty[2]
```

The **Pasture Status** is split into two converters depending on whether it is positive or negative. **Surplus** holds the

Pasture Status if it is positive, while **Deficit** holds the **Pasture Status** if it is negative. This separation is made because the **Surplus** and **Deficit** are treated differently by the decision making process. If there is a **Surplus**, then the herders choose a share called **Bonus Share**. If there is a **Deficit** then the herders choose a share called **Burden Share**. The **SVO** converter holds the social value orientation of each of the herders, while the **Uncertainty** converter holds the uncertainty that the herders harbor about the size of the **Surplus** and **Deficit**. Both **Uncertainty** and **SVO** affect the size of the shares that the herders decide on. When faced with uncertain resources, I assume that the herders will choose the more favorable estimates as suggested by research on uncertainty. Social value orientation is a preference for self/other outcomes. The **SVO** converter holds the outcome preferred for the other. It is assumed that the preferred outcome for the self is 1. The values that the SVO will generally hold are 1,0, and -1, corresponding respectively to cooperative, individualistic, and competitive herders.

I make some assumptions about how **Uncertainty** is applied in the decision mechanism. I assume that given the existence of **Uncertainty**, herders will hope for the smaller estimate of the **Deficit** and the larger estimate of the **Surplus**. Thus if there is an **Uncertainty** of 5% about the

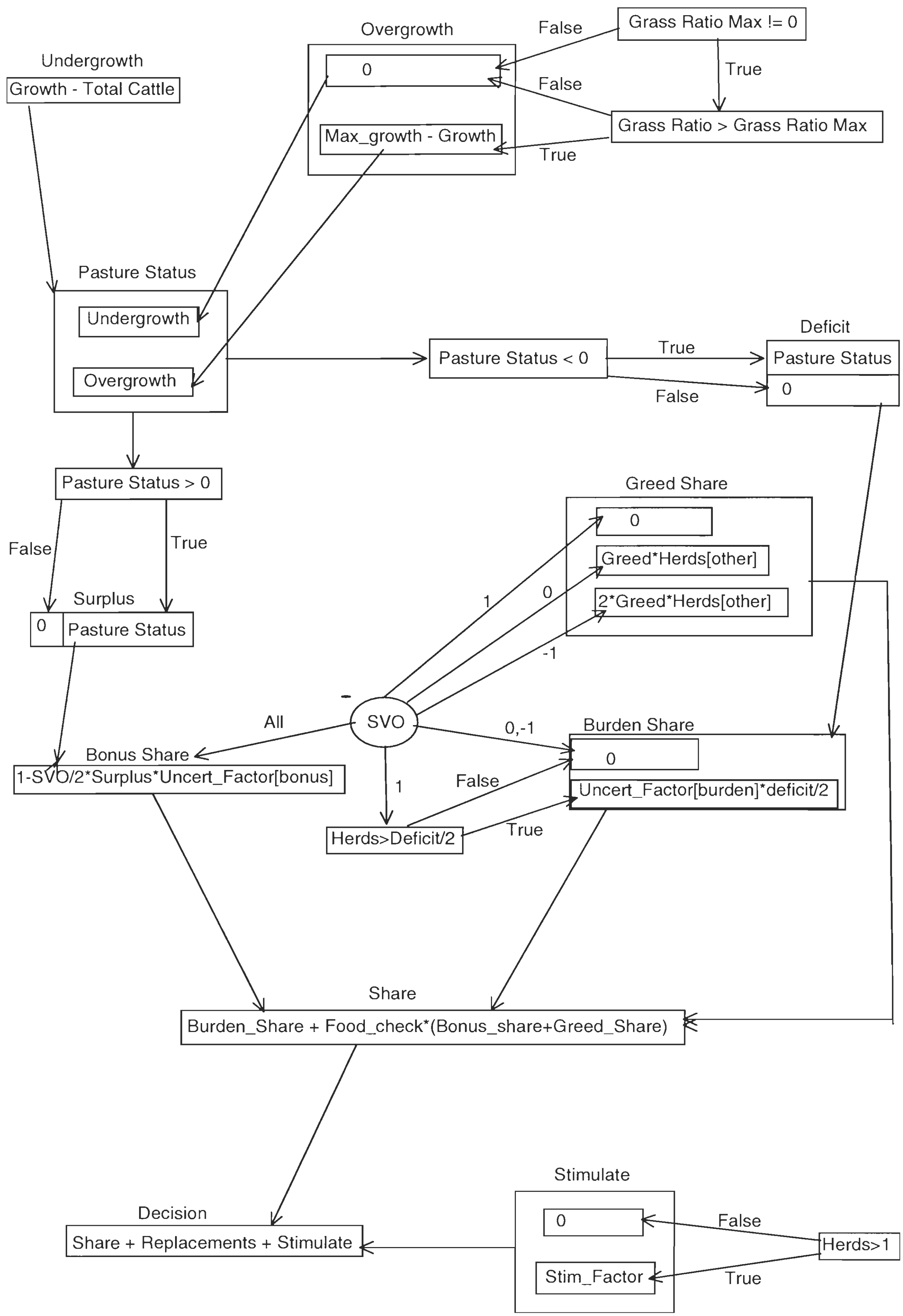
Pasture Status, then the herders will assume the values of 0.95***Deficit** and 1.05***Surplus** to represent the actual quantities. It is these transformed values that will be considered as the quantities being split for the **Bonus Share** and **Burden Share**. The converter **Uncertain Factor** is a two dimensional array with four components, used to define the transformation of the **Surplus** and **Deficit**. One dimension is for the herders and another dimension for whether the uncertain quantity is a **Surplus** or **Deficit**. For each herder, one element holds the estimated fraction of the Surplus, and another holds the fraction of the **Deficit**. By multiplying the **Surplus** or **Deficit** by the appropriate component of **Uncertain Factor**, the optimistic estimations are achieved.

In Addition, it is necessary to make some assumptions about how **SVO**, is applied to the decisions of the herders. I assume that when there is a **Deficit** on the pasture, or there are more cattle than the growth can support, then the herders with a **SVO** of 0 or less will not contribute by removing some of their cattle from the herd. Herders with an **SVO** of higher than 0 will remove **SVO**/2 of the **Deficit** from their herds. So cooperators with an **SVO** of 1 will consider a **Burden Share** of half the **Deficit**. I also assume that herders choose 1-**SVO**/2 of the **Surplus**. In this way, cooperators take ½ of the **Surplus**, individualists take all of the **Surplus**, and competitors take 1½ of the **Surplus**. Whenever a combination of herders other than two cooperators exists, the herders will be playing a game best described as Chicken. Chicken is a game where two opponents both have two options: fold and loose some, or stand. If both opponents stand, then they both loose all. If an opponent folds then they loose some, but not all. If one herder is a competitor and the other is a cooperator then, after they split a surplus, there will be a **Deficit** on the pasture. In this case, the game of Chicken is rigged so that the cooperator will always fold and bear the **Burden Share**, while the competitor sails free.

In order to preserve the integrity of the model, a condition on the **Burden Share** is made. A Boolean logic statement in the **Burden Share** definition prevents a herder from removing more cattle than they have in **Herds**, which keeps the **Herds** stock from going negative.

The **Greed Share** represents action taken due to either greed or lack of value for another person's outcome. It is also an action that initiates the game of Chicken. The **Greed Share** of a herder is considered a fraction of the size of the herd belonging to the other herder. In this way, the Greed Share is related to the concept of greed. However, in addition, the **Greed Share** may be considered a strategy to cower the other herder into submission, and dominate the pasture. The **Greed Share** is defined as **Greed Fraction**[self]***Herds**[other]. Only Herders with an **SVO** of zero or less are assumed to have a **Greed Share**. The **Greed Fraction** is weighted such that individualists have a **Greed Fraction** of **Greed**, while competitors have a **Greed Fraction** of 2***Greed**, and cooperators have a **Greed Fraction** of zero. The converter **Share** holds the sum of **Bonus Share**, **Burden Share**, and **Greed Share**, the three types of shares, and is the final amount that will be added to the **DECISION** along with the **Replacements** and **Stimulate**. An important condition related to the state of the pasture is imposed on **Share**. **Food Check** is a converter that contains a value of zero if the **Availability** is less then one, and contains a value of 1 otherwise. When summing the three components, the components **Bonus Share** and **Greed Share** are multiplied by the **Food Check** to ensure that cattle are not added to the pasture when there is not enough food there to feed them. This condition helps prevent the **Grass** stock from going negative, and helps the model remain more realistic in addition. The following picture helps clarify these relations by providing an additional visual presentation of some of the logic relations.

Fig.3.14


Overgrowth
False
Grass Ratio Max != 0
Undergrowth
Growth - Total Cattle
0
False
True
Grass Ratio > Grass Ratio Max
Max_growth - Growth
True
Pasture Status
Undergrowth
Overgrowth
Pasture Status < 0
True
Deficit
Pasture Status
0
False
Pasture Status > 0
Greed Share
0
Greed*Herds[other]
2*Greed*Herds[other]
False
True
Surplus
0
Pasture Status
1
0
-1
SVO
All
0,-1
Burden Share
0
Bonus Share
1-SVO/2*Surplus*Uncert_Factor[bonus]
1
False
Uncert_Factor[burden]*deficit/2
Herds>Deficit/2
True
Share
Burden_Share + Food_check*(Bonus_share+Greed_Share)
Stimulate
Decision
0
False
Share + Replacements + Stimulate
Herds>1
Stim_Factor
True

Discussion

The explanation of the model development has concluded. Before moving on to present results from the model, I will summarize and discuss the developed model. A major theme throughout the model is an assumption that herders will not add cattle to the pasture if there is not enough food available. This is an assumption that provides a realistic check on the actions of the herders, and in addition helps the model avoid some undesirable effects such as a negative **Herds** or **Grass** stock.

Besides the definition of **Greed Share**, there is not significant interaction between the two herders. The two herders for the most part follow blind strategies that are defined by their **SVO**. The game of Chicken has special significance to the structure of the model. Effectively, any combination of herders other than two cooperators will play the game of Chicken. The herders do not develop strategies to counter the moves of the other herder. An example of the results of this is that cooperators are always sure losers when playing against individualists or competitors.

Several cognitive assumptions are that the herders are capable of discerning increases and decreases in the growth rate on the pasture, and that they are able to spot the turning point where further growth of grass is inefficient.

Because **Uncertainty** was applied after the **Pasture Status** determination, the effects of true uncertainty about the growth rate of grass are not included in the model. However, the effects would still be inflated desirable outcomes and deflated undesirable outcomes. This misplacement of the effects of uncertainty on perception would be amendable to correction with further sophistication of the model.

A problem with the **Stimulate** addition to **DECISION**, is that no conditions are included which reduce **Stimulate** once the optimal levels of grazing are achieved. This will generally be a minor problem, but may have negative impacts on model performance when herders have two different values for **Stimulate**. Solutions for the improvement of this problem have not been investigated.

Because of the complexity of framing, this heuristic was not included in the model. It is not so much as what to do when a herder is in a gain or loss frame that is difficult, but rather the determination of *when* a herder would be in a gain frame or loss frame. Searches of available literature did not provide any indications that an amendable solution to this question is available.

Results

From the model developed, several types of patterns could be expected. Competitors and individualists would be expected to outdo cooperators and take over the pasture. The results of two cooperative herders are expected to outdo any other combination. In any combination where neither herder is a cooperator, a crash of the pasture is expected since neither backs out of the game of Chicken. Increases in **Uncertainty** or **Stimulate** should decrease the profits of herders, by slowing growth, or speeding up the decimation of the grass. When neither herder is a cooperator, an increase in **Greed** should speed up the decimation of the pasture. When only one herder is a cooperator, and increase in greed should speed up the game of chicken so that the pasture is dominated more quickly by one of the herders.

Unless otherwise noted, the following values will be used for model parameters: **Uncertainty** = 5%, **Stim Factor** = 1, **Greed** = 2%

To start, I will show results when the six different SVO combinations are used.

Cooperator Cooperator: The Graph below shows the model run for 1000 days, It reaches equilibrium at the optimal grass quantity, and total herd size. The final value of **Total Profit** for each herder is 247.

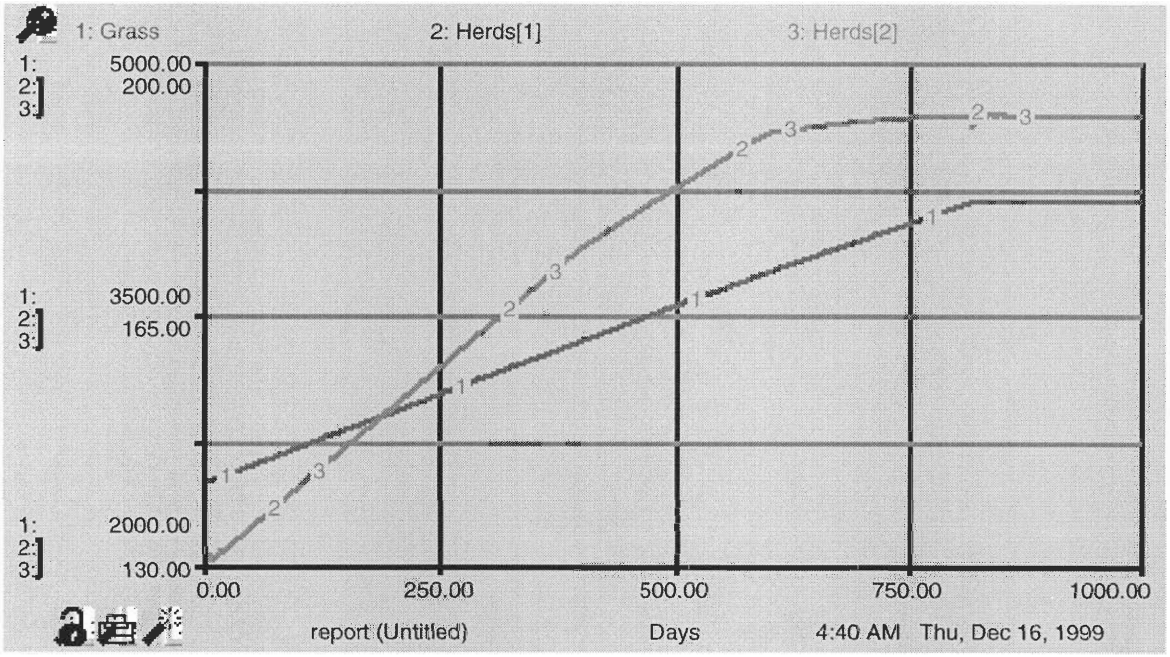


Fig. 4.1

Individualist Individualist: When both herders are individualists, the herd sizes and **Grass** display a classic overshoot and collapse pattern. The initial overshoot and collapse is followed, not surprisingly, by a periodic overshoot and collapse pattern. They both achieve **Total Profits** of -9 ending with a loss.

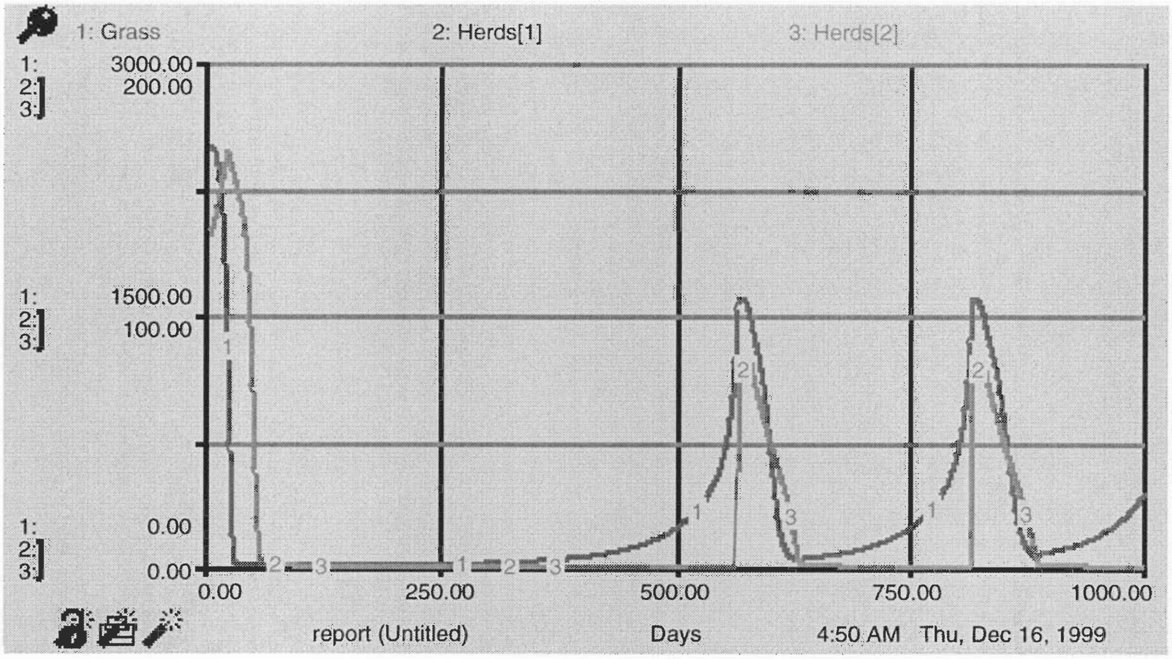


Fig. 4.2

Competitor Competitor: Two competitors decimate the pasture even faster than two individualists, and in addition, loose more money each. Both herders end up with a **Total Profit** of -15. An interesting double peak phenomena emerges with the latter periodic overshoot and collapse pattern.

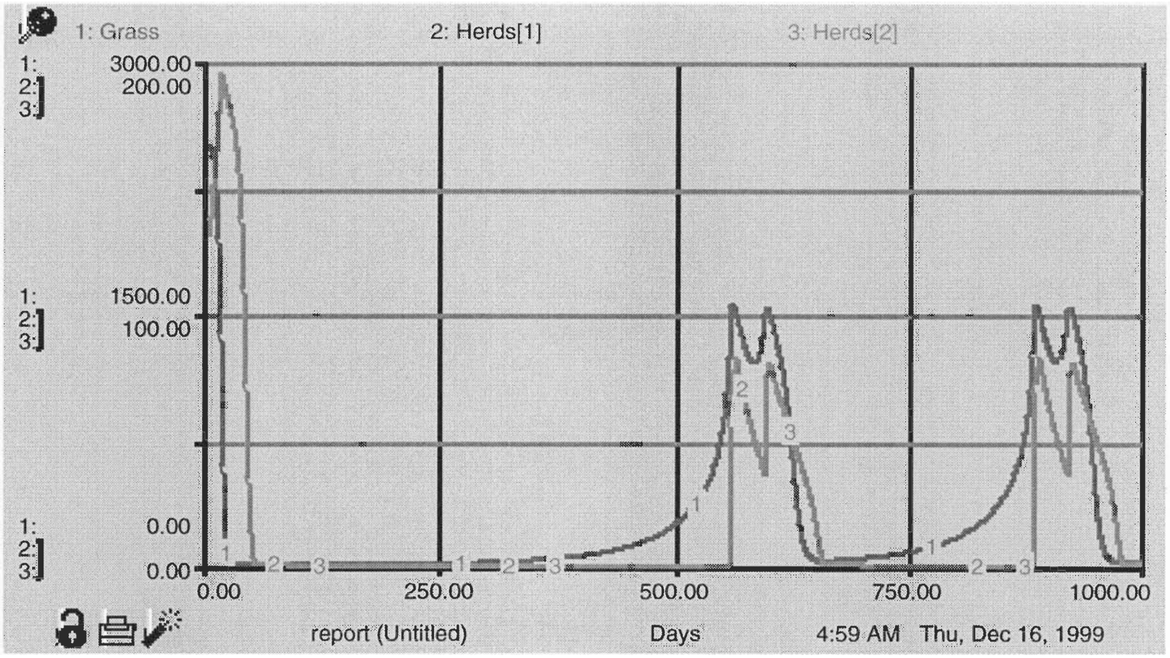


Fig. 4.3

Cooperator Individualist: The cooperator, Herds[1], looses the pasture to the individualist Herds[2]. After about 2000 days the pasture will stabilize to an optimal growth rate, and all of the cattle will belong to Herd[2]. The cooperator comes out with a profit of -5 while the individualist makes 408.

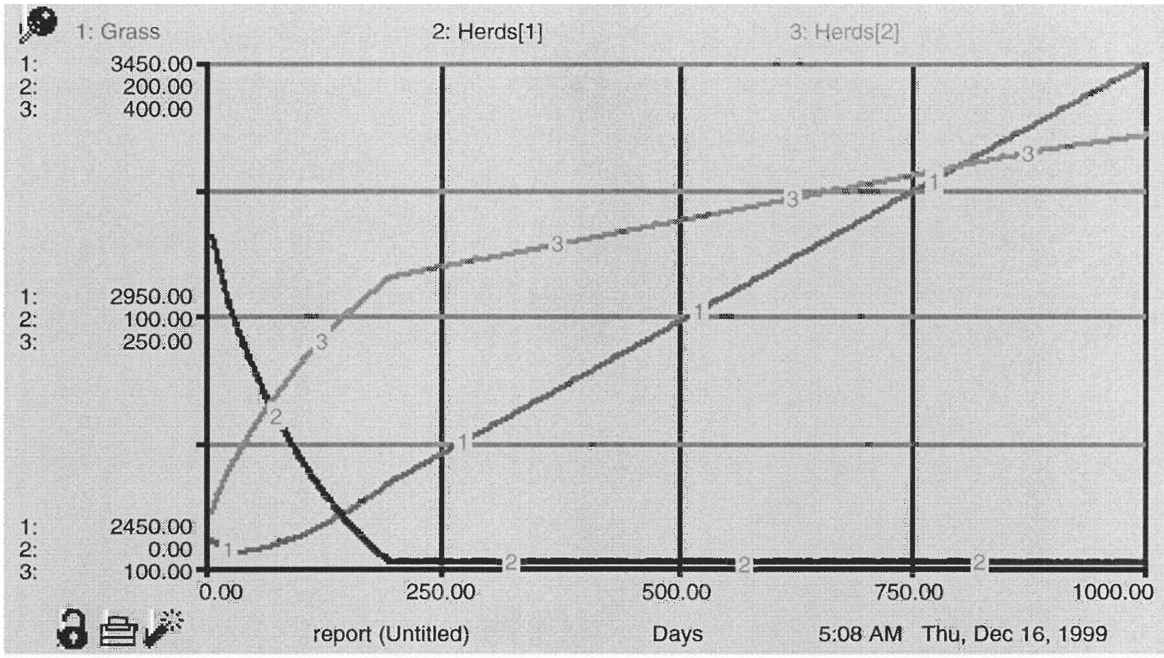


Fig. 4.4

Cooperator Competitor: The pattern with a cooperator and competitor is similar to the cooperator and individualist, except that the competitor wins the game of Chicken much faster, and is slower to reach the optimum capacity of the pasture at 3000 days. The final profits for this pair is -14 for the cooperator and 384 for the competitor.

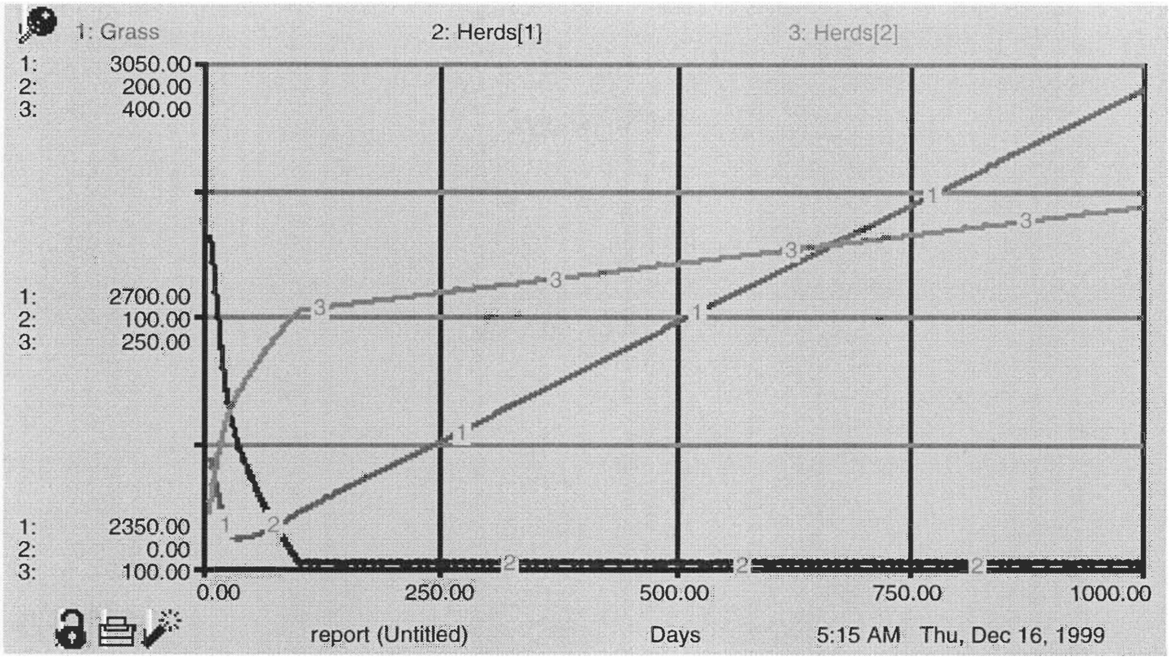


Fig. 4.5

Individualist Competitor: The individualist competitor pattern is very similar to individualist individualist or competitor competitor. However, the competitor plays a harder game of Chicken than does the individualist. This strategy does not work to the advantage of the competitor since he comes out with a profit of -15 while the individualist ends with -8.

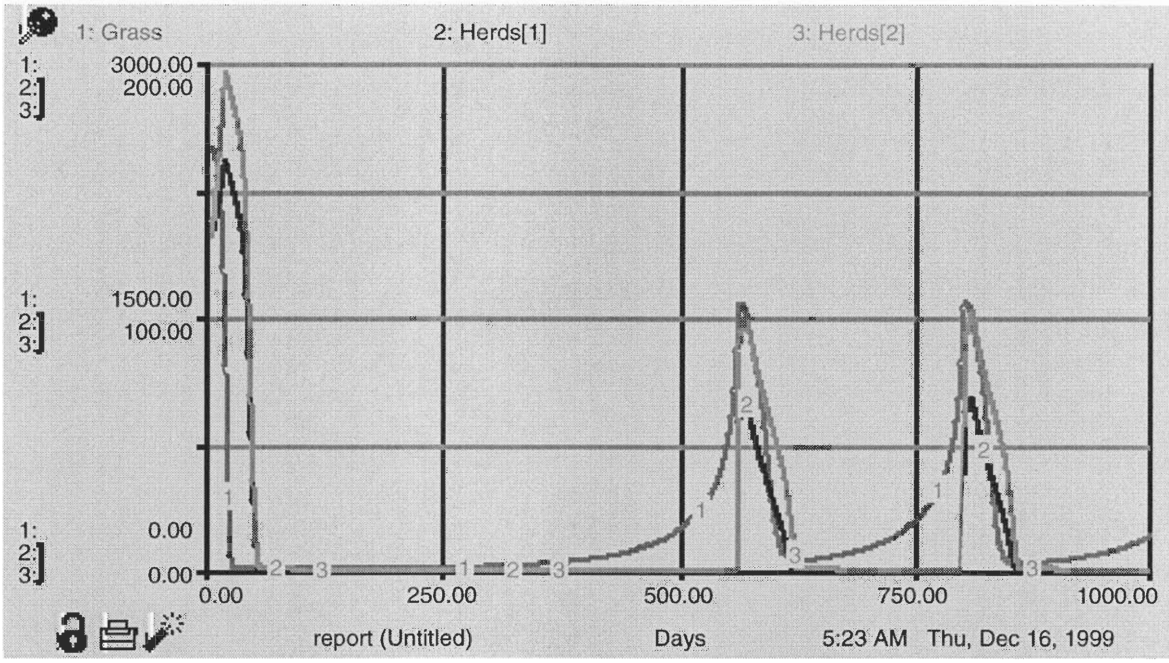


Fig. 4.6

The **SVO** combinations have, in general, produced expected results. Next, effects from varying the **Uncertainty**, **Stimulation**, and **Greed** will be presented.

The following comparative graph show the development of the grass for two cooperators when **Uncertainty** is at 0 (1:Grass), and at 0.5 (2:Grass). With higher uncertainty, the pasture is slower to mature. The herders with an **Uncertainty** of 0 each end with a profit that is 13 higher than the herders with higher **Uncertainty**.

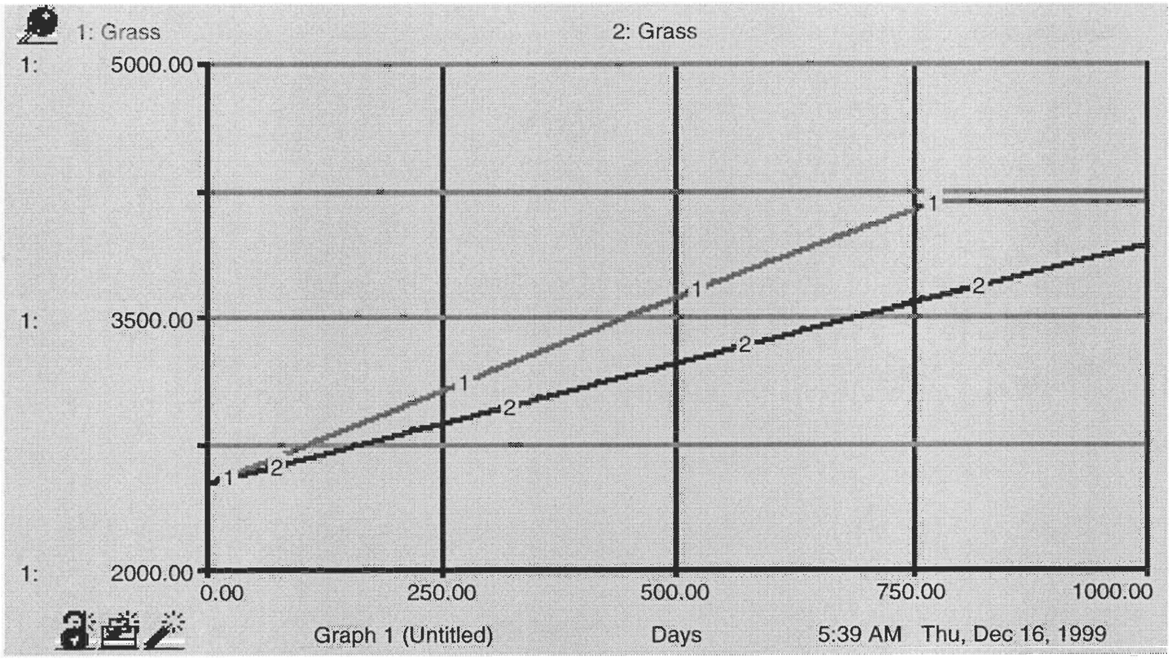


Fig. 4.7

The follow graph shows **Grass** for two different settings of **Stimulate** when the two herders are both individualists. The first setting for **Stimulate** is -1 (1:Grass) and the second setting is -0.1 (2:Grass). As predicted, an increase in **Stimulate**, increases the decimation of the pasture. The value of **Stimulate** is a powerful parameter, and can even cause two competitors to not decimate the pasture, if decreased sufficiently.

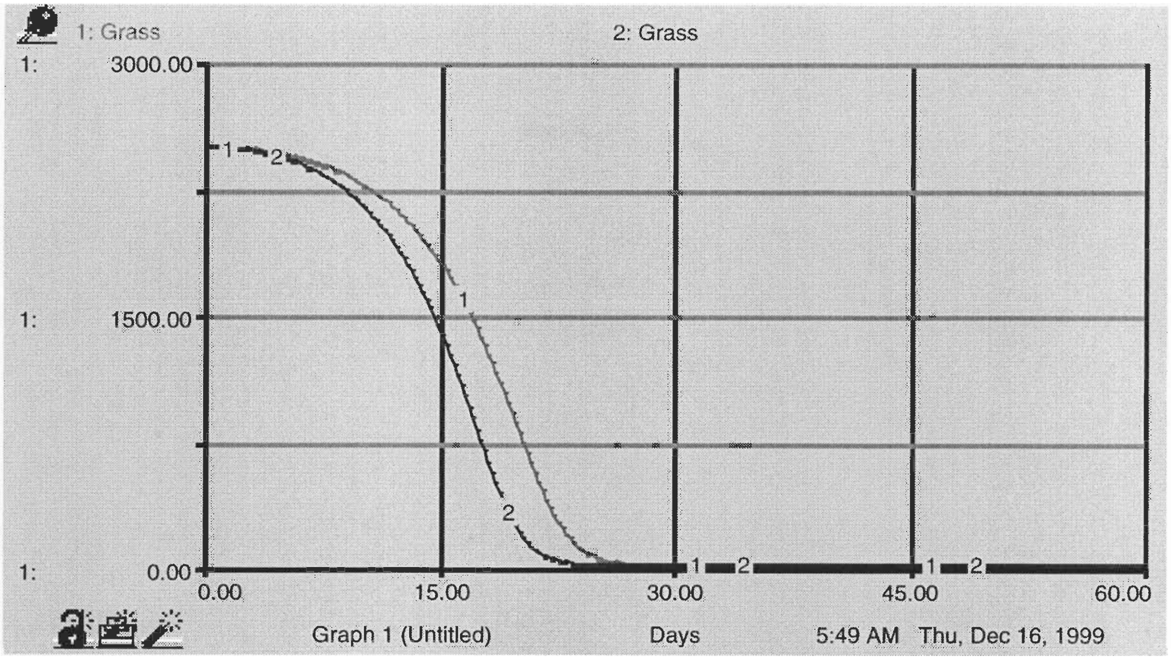


Fig. 4.8

The graph below shows the results when there are two competitors, and **Greed** is set at 0.02 (1:Grass) and 0.1 (2:Grass).

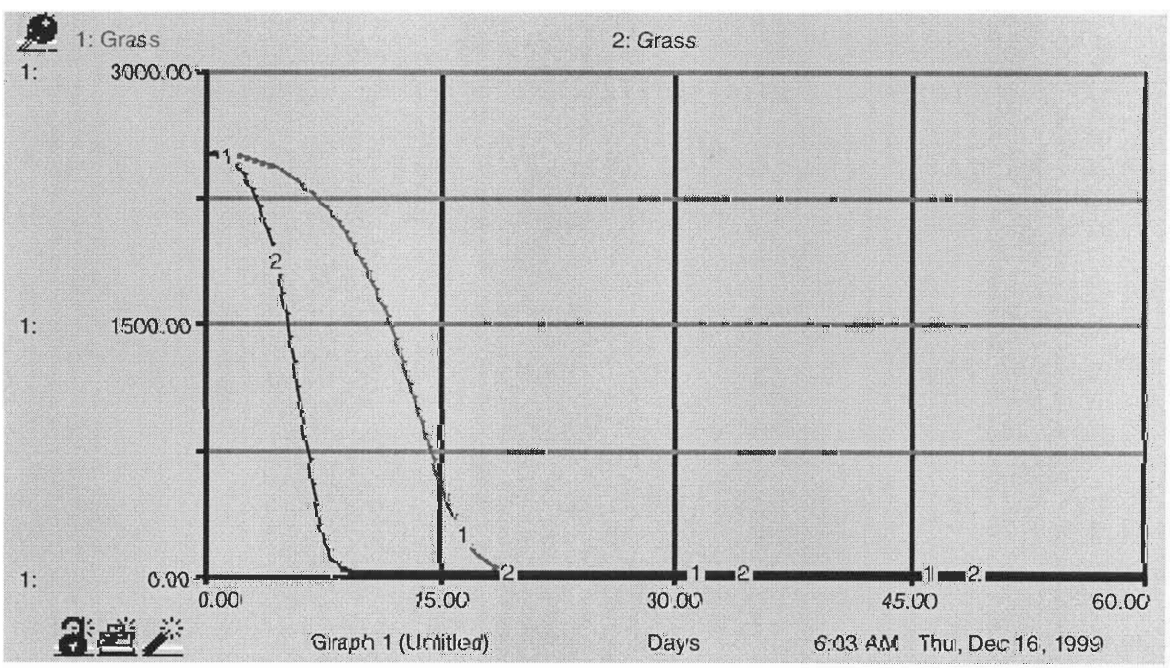


Fig. 4.9

Conclusions

This research project gave a historical and conceptual overview of ideas related to resource allocation, and developed a system dynamics model, which utilized some of those ideas. Providing a basis for the inclusion of psychological and sociological factors in theoretical decision mechanisms for people was an important aspect of this research project. The concepts of economic rationality were compared with findings from psychological and sociological research to show an incompleteness of the economic rationality method, and conflicts between economic rationality and empirical findings. To provide a definite foundation for an alternative to an economic rationality decision strategy, empirical findings documenting factors affecting decision-making were reviewed.

One goal of this research project was to develop a system dynamics model of two herders on a pasture with the inclusion of decision concepts from psychology and sociology. Some important concepts included in the model were heuristics related to decision making, which have been documented in psychological and social literature. The inclusion of psychological factors in the model provided fruitful results. With the inclusion of uncertainty, a form of temporal discounting, and social value orientation, the developed model was able to exhibit several patterns of behavior that empirical research suggests should exist in the model scenario.

The experimental guidelines for the behavior that the model should produce are limited to a few general relations, since searches of the literature provided no definite historical pattern that should be mimicked. This lack of historical data is a major weakness of the developed model, since without the reproduction of a definite expected behavior, the model is less trusted to produce viable results. In addition, there are many heuristics that have been documented, and only a few were included in the model. It is possible that heuristics not included in the model could have an important effect, and that some of the heuristics included may be less important than heuristics that have not been included. Also, the suggested decision process may be inaccurate since the empirical support for the mentioned heuristics was achieved by social dilemmas created in a laboratory, and not in a situation identical to the model scenario. In addition, the concept of temporal discounting was simplified in the model due to the complexity of implementing the empirically supported function. Instead, a constant discounting factor was used. And finally, the model is only a model and is not a theory. The model is intended to be representative of the model scenario rather than definitive.

The developed system dynamics model could be applied to many situations where two people are sharing a renewable resource. An interesting application, would be in testing the outcome the model predicts in a social dilemma with experimental results when two people share a resource. This type of testing could produce findings on the accuracy of the model, and model concepts, as well as the on the accuracy of psychological tests used to estimate Social Value Orientation, extent of uncertainty, and degree of temporal discounting. It is possible that a model such as this, in combination with psychological assessment of individuals may be a significant predictor of how successfully two people will complete an interdependent task. Decisions on what two people would best to team up for a particular task could be aided by such predictions. The methods employed by this model could also have some applicability to negotiation between two parties facing a situation where the gain of one party could be at the expense of the other party. Examples of such negotiations, are the development of production contracts between companies, the negotiation of trade agreements between countries, and the negotiation between environmental regulators and special interests. Often such negotiations occur between a limited number of people representing larger entities. Thus, the model may be applicable in certain instances. However such use of the model in such instances would warrant caution and a reassessment of the model construct.

The developed model could be refined by inclusion of additional heuristics such as framing. The representation of temporal discounting and other heuristics in the model could be refined to more accurately represent empirical findings. In addition, further research in psychology and sociology may show that there are other relevant factors which should be included in the model.

It is my opinion that a productive use of system dynamics modeling in social dilemmas might be keyed toward the laboratory situations and methods that are used in experimental research of heuristics. Such a development would allow a more thorough correspondence between measured data, and psychological theory. This mode of development may be more desirable at this time, given the limited extent of relevant psychological theory. A form of the model could be developed that is set in the context of the specific format of social dilemmas used by researchers in documenting relevant heuristics. Such a model could produce results that are amendable to comparison with measured data, and provide feedback on the accuracy of theories in psychology and sociology. I view system dynamics as a promising tool in developing theory on empirical psychological and social research that is more convenient to develop than a classical differential equation format of theory.

References

(1)Author not listed(1994); “The human factor: rational economic man”. The Economist; vol. 333, Dec. 24 1994, p. 90.

(2)Bazerman, Max H. & Tenbrunsel, Ann E. & Wade-Benzoni, Kimberly(1998);”Negotiating with yourself and losing: Making decisions with competing internal preferences”. The Academy of Management Review, Academy of Management, Missisipi State; April 1998, vol. 23, issue 2, p. 225-241.

(3)Bernstein, Peter L.(1997);”How we take risks”. Across the Board, New York; Feb. 1997, vol. 34, issue 2, p. 23-34.

(4)Conlisk, John(1996); "Why bounded rationality?". Journal of Economic Literature. vol. 34, issue 2, Jun 1996, p. 669.

(5)Doucouliagos, Chris (1994); "A note on the evolution of Homo Economicus". Journal of Economic Issues; vol. 28, issue 3, Sep 1994, p. 877.

(6)Dreu, Carsten K. W. De & McCusker, Christopher(1997); “Gain-Loss Frames and Cooperation in Two person Social

Dilemmas: A Transformational Analysis”. Journal of Personality and Social Psychology; 1997, vol. 72, No. 5, p. 1093-1106.

(7)Dugatkin, Lee Alan (1999); "Cheating Monkeys and Citizen Bees: The Nature of Cooperation in Animals and Humans"[book]. The Free Press, New York.

(8)Gifford, Robert (1997); "Environmental Psychology: Principles and Practice"[book]. Chapter 14, p. 344-379.

(9)Gonzalez, Richard, & Wu, George(1999); “On the Shape of the Probability Weighting Function”. Cognitive Psychology; 1999, vol. 38, p. 129-166.

(10)Hardin, Garrett(1968); "The Tragedy of the Commons". Science; vol. 162, Dec. 1968, p. 1243-1248.

(11)Harvey, John T.(1998);”Heuristic judgement theory”. Journal of Economic Issues; 03-01-1998, vol. 32, p. 47.

(12)Kiel, L. Douglas & Seldon, Barry J.(1998); "Measuring temporal complexity in the external environment: Nonlinearity and the bounds of rational action". American

Review of Public Administration; vol. 28, issue 3, Sep. 1998, p. 246-265.

(13)Laibson, David I. & Repetto, Andrea & Tobacman, Jeremy(1998);"Self-Control and Saving for Retirement". Brookings Papers on Economic Activity, Washington; 1998, issue 1, p. 91-196.

(14)Laibson, David(1998);"Life-cycle consumption and hyperbolic discount functions". European Economic Review; 1998, vol. 42, p. 861-871.

(15)Martin, Roderick(1993); "The new behaviorism: A critique of economics and organization". Human Relations; vol. 46, issue 9, Sep. 1993, p. 1085

(16)Petry, Nancy M. & Casarella, Thomas(1999);"Excessive discounting of delayed rewards in substance abusers with gambling problems". Drug and Alcohol Dependence; 1999, vol 56, p. 25-32.

(17)Platow, Michael J. & Shave, Roger(1995);"Social value orientations and the expression of achievement motivation". The Journal of Social Psychology; 02-01-1995, vol. 135, p. 71.

(18)Repetto, Robert(1999); "Give fishermen a stake in the sea". The Boston Globe (a daily newspaper); August 24, 1999, vol. 256, number 55, p. A19.

(19)Roch, Sylvia G. & Samuelson, Charles D.(1997);"Effects of Environmental Uncertainty and Social Value Orientation in Resource Dilemmas". Organizational Behavior and Human Decision Processes; June 1997, vol. 70, No. 3, p. 221-235, Article No. OB972707.

(20)Suleiman, Ramzi & Budescu, David V.(1999); "Common Pool Resource(CPR) Dilemmas With Incomplete Information"[article]; Budescu, David V. (Ed.) & Erev, Ido (Ed.) et-al.(1999); "Games and Human Behavior: Essays in honor of Amnon Rapoport"[book]. Chapter 16, p. 387-409.

(21)Van Lange, Paul A. M. & Kuhlman, D. Michael(1994);"Social Value Orientations and Impressions of Partner's Honesty and Intelligence: A Test of the Might Versus Morality Effect". Journal of Personality and Social Psychology; 1994, vol. 67, No. 1, p. 126-141

(22)Van Lange, Paul A. M. & Liebrand, Wim B. G. & Kuhlman, D. Michael(1990); "Causal Attribution of Choice Behavior in

Three N-Person Prisoner’s Dilemmas”. Journal of Experimental Social Psychology; 1990, 26, p34-48.

(23)Warry, Chris J. & Remington, Bob & Sonuga-Barke, Edmund J. S. (1999); "When More Means Less: Factors Affecting Human Self-Control in a Local Versus Global Choice Paradigm". Learning and Motivation; vol. 30, p. 53-73.

(24)Wiener, Joshua, & LyleDoescher, Tabitha A.(1994);”Cooperation and expectations of cooperation”. Journal of Public Policy & Marketing, Ann Arbor; Fall 1994, vol. 13, issue 2, p. 259.