RURAL DEVELOPMENT CHALLENGES: SYSTEM DYNAMICS *EX ANTE* DECISION SUPPORT FOR AGRICULTURAL INITIATIVES IN SOUTHERN MEXICO

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ABSTRACT

A persistent problem facing rural communities in the Gulf region of Mexico is the low profitability of agriculture. In order to improve the short and long-term economic security of households in these rural communities, value addition to agricultural products is proposed by farmers and by professionals for niche markets. Correspondingly, collective action in the form of rural marketing cooperatives may provide a means to augment household profits from sales of value-added products.

The *ex ante* assessment of this challenge, like others that are similarly complex, is undertaken using system dynamics methods. In response to an institutional request, researchers and development practitioners at the *Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias* (INIFAP) Xalapa team were trained in introductory systems thinking and dynamic modeling techniques during a three-month, institutional capacity-building course. When combined with INIFAP's repertoire of technology and data assessment tools, short course results suggested that system dynamics could help fortify institutional capacity, especially *ex ante* problem assessment capabilities.

A form of participatory model building in which small teams of course participants complete the modeling process for selected dynamic problems was incorporated into the short course. The teams achieved varying success in the study and development of conceptual models and in building incipient simulation models. The relative success of these learning-by-modeling problem assessments reflected favorably on the high initial capacity and motivation of the INIFAP-Xalapa team. This interdisciplinary team could

become an innovator in leading group model building initiatives to develop more insightful alternative approaches for confronting complex agricultural research and development problems and issues.

Course participants also completed group model building exercises and contributed expert knowledge to improve a system dynamics model designed to assess impacts on farmer profits of value-added agricultural production by a smallholder marketing cooperative. The dynamic biophysical and socioeconomic model consists of nine components that represent the aggregate community flock and a value addition and marketing cooperative. The primary objective of the model was to assess strategies to increase the profitability of caprine production in highland communities. This adaptable model was designed as an *ex ante* impact assessment mechanism for INIFAP to evaluate policies and the associated opportunities and limitations of value addition.

The analysis indicates that manufacture of value-added products from goat's milk by a rural dairy cooperative could increase community net income from caprine activities under a wide variety of environmental and market conditions. Increases in net income would be especially important during the dry season, when cooperative dividend payments could partially mitigate seasonality from typical other income sources. Model sensitivity analyses demonstrated that the exogenous effects of seasonal rainfall on forage supply are more important to system performance than endogenous feedback within the system. System performance was measured primarily by elements that likely influence farmer and cooperative decision-making: profitability of the community goat flock, cooperative solvency time, dividend payments, and cancelled orders for aged cheese.

The analysis also indicated potential risks and those factors that could limit cooperative success. The most important of such factors include the size and reliability of the market for premium aged cheese, the cooperative's payments for milk and dividends, milk production costs, cheese production costs, and the composition and productivity of the goat flock. These factors, and forage quality, should receive priority in future research and implementation.

BIOGRAPHICAL SKETCH

Keenan McRoberts grew up on a farm and exotic animal ranch in western Nebraska. He received his B.S. in biochemistry from the University of Nebraska-Lincoln. He then worked from 2001 to 2005 in northern Nicaragua as an Agriculture Extension Volunteer and Agriculture Technical Trainer with the Peace Corps. He entered the MPS program in International Agriculture and Rural Development at Cornell University in 2006. He started a doctoral program in Animal Science at Cornell University in summer 2009.

To the INIFAP Team in Xalapa, Veracruz.

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Very special thanks go out to my parents Wayne and Cathie and my sister Carmen and brother-in-law Ryan for all the love and energy put toward being patient and supportive of me throughout this process! Thank you so much.

Many thanks go out to my advisors, Dr. Robert Blake, Dr. Charles Nicholson, and Dr. Terry Tucker. Your patience, support, and guidance have been instrumental in my thesis progress and personal development. Dr. Blake masterminded the idea to undertake summer research by offering the introductory course in system dynamics to INIFAP, which made the whole project an enjoyable and successful one. In addition, Dr. Nicholson's dedication, constructive questioning, and passion for system dynamics in international agriculture applications have constantly been motivating factors for me during the past few years. My former officemate and friend Omar Cristóbal was also a source of mutual personal and professional support as we plodded semi-simultaneously through our master's projects.

Finally, thank you to the Latin American Studies Program of the Mario Einaudi Center for International Studies at Cornell University for providing me with a summer travel grant to support my travels for collaboration with INIFAP in Xalapa, Veracruz.

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LIST OF ABBREVIATIONS

AEM	Applied Economics and Management
CIP	Centro Internacional de la Papa
DMNL	Dimensionless
GGAVATT	Grupo Ganadero de Validación y Transferencia de Tecnología
GIS	Geographic Information System
IARD	International Agriculture and Rural Development
INIA	Instituto Nacional de Investigaciones y Tecnología Agraria y Alimentaria de España
INIFAP	Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias
LADIGS	Laboratorio de Agromapas Digitales
SAGARPA	Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación
TIES	Training, Internships, Scholarships and Exchanges
USAID	U.S. Agency for International Development
ZIDZ	Zero if Divided by Zero

PREFACE

This project had its origin in the author's experience working with rural communities and numerous governmental and non-governmental organizations as a Peace Corps Volunteer and Peace Corps Technical Trainer in Nicaragua. Upon arrival at Cornell University he had a strong desire to undertake a practical project that could contribute to an international organization or to a community in Latin America. His goal was to achieve more than just earning a degree, but also to contribute with capacity building assistance at the request of an organization or a community.

The opportunity emerged when the author began to work with the multi-institutional Training, Internships, Exchanges and Scholarships (TIES) Mexico project, *Decision Support of Ruminant Livestock Systems in the Gulf Region of Mexico*. The decision to focus on system dynamics applications was made during his first semester at Cornell when he was introduced to the use of system dynamics for agricultural development during the Applied Economics and Management (AEM) 494 course, *Introduction to System Dynamics Modeling*. The course provided evidence and motivation for creating a system dynamics platform for critical thinking in a rural development forum. The author simultaneously enrolled in a two-course package, International Agriculture and Rural Development (IARD) 402/602 Mexico, and participated in the IARD 602 field laboratory in Mexico in January 2007. During the two-week field experience in Mexico, he became acquainted with TIES collaborator Gabriel Díaz Padilla and the rest of the *Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias* (INIFAP) mountain research team in

Xalapa, Veracruz, with whom the foundation for future collaboration was established.

Background about INIFAP

INIFAP is a Mexican governmental institution dedicated to research and development of agricultural technologies. The INIFAP office in Xalapa, Veracruz is the administrative base for numerous agricultural research programs. Its *Campo Experimental* in Teocelo focuses on the viability of different methods of diversifying the traditional coffee plantation by planting in association with timber species, ornamental plants, and silvopastoral systems with sheep. In a separate INIFAP project led by the *Laboratorio de Agromapas Digitales* (LADIGS), the *Campo Experimental* is among the Mexican leaders in spatial modeling of crop production potential using Global Information Systems (GIS) methods. LADIGS also develops regional maps of historical and projected climatic trends.

The *Campo Experimental* executed a mountain micro-watershed development project from 2003 to 2008. Different from most INIFAP programs and the institution's mandate, community development and extension were important components of this project. Funding for the micro-watershed project was provided by the *Instituto Nacional de Investigaciones y Tecnología Agraria y Alimentaria de España* (INIA) and implemented collectively by INIFAP and the *Centro Internacional de la Papa* (CIP). The project was designed to develop technology and agricultural alternatives that will improve sustainable management of key micro-watersheds while raising the standard of living in participating communities. It focused on four branches of rural development: agronomic, economic, health, and socio-cultural development

(Díaz Padilla et al., 2006). Key activities in the project included: low-cost basic infrastructure (e.g., high efficiency wood stoves, compost latrines, and greenhouses), integrated patio management, family health and nutrition, ruminant livestock production, improved forages, and staple grains management. These components were jointly selected by INIFAP personnel and members of three communities—Micoxtla, Mesa de Laurel, and Ingenio del Rosario—during the diagnostic phase of the project in 2003.

Similar projects were concurrently led by Díaz Padilla in priority watersheds in the states of Durango and Chiapas. The three watersheds were selected based on common problems: unemployment, low incomes, environmental degradation, and food insecurity (Díaz Padilla et al., 2006). As of January 2008, INIFAP's watershed work in Veracruz was undergoing a transition toward intensive micro-watershed investigation to improve water management in the Gavilanes River (Coatepec) micro-watershed.

INIFAP/Cornell University Collaboration

The INIFAP *Campo Experimental* in Xalapa, Veracruz collaborated with Cornell University on the United States Agency for International Development (USAID) Training, Internships, Exchanges and Scholarships (TIES) Mexico initiative. As part of the TIES program, Gabriel Díaz Padilla attended Cornell for a semester-long sabbatical in 2005. During that time, he was introduced to systems science applications and dynamic modeling during the introductory system dynamics course. The sabbatical generated further interest for INIFAP researchers and technicians to collaborate with Cornell University.

Later, INIFAP helped organize and received three study groups comprising students and faculty from Cornell University, the *Universidad*

Veracruzana, and the *Universidad Autónoma de Yucatán* during the IARD 602-Mexico field courses in 2006, 2007, and 2008. The author was a participant and then a facilitator during the field courses in 2007 and 2008. Following the 2007 field trip, he worked with Díaz Padilla and advisors Robert Blake, Charles Nicholson, and Terry Tucker to explore options for coordinated field research with the INIFAP team.

INIFAP suggested the need to further develop agricultural value-addition components of their mountain project. One of the more important income generation activities in Veracruz highlands communities is the sale of goat’s milk. However, low profits suggested a potential need to explore options to derive high-value products from the milk produced. This priority option, also identified by community members, became a master example for the author’s exploratory system dynamics work during a second course in system dynamics applications (AEM 700). In this course, a preliminary model addressing value addition to goat’s milk by cheese manufacture was developed as a tool for pedagogical and analytical purposes in preparation for summer 2007 field activities with INIFAP in Xalapa, Veracruz.

The INIFAP team also expressed interest in receiving a course on systems thinking and modeling using system dynamics methods. At their request, the author taught an introductory system dynamics course in Xalapa. The three-month course, conducted from June to September 2007, was titled, *Introducción al Pensamiento Sistémico y Modelación Dinámica de Problemas* (Introduction to Systems Thinking and Dynamic Problem Modeling). This course emulated the system dynamics curriculum at Cornell University. It provided INIFAP with valuable learning and insight about potential agricultural and rural development applications of system dynamics. The course fulfilled the desired institutional capacity building component of the author’s master’s project. Based on INIFAP’s institutional goals and participant interests, team model building activities were undertaken as an important course component.

The timeline trajectory to thesis project completion is described below:

2006

- August: The author initiated graduate studies at Cornell University and enrolled in Introductory System Dynamics.

2007

- January: Possibilities for a collaborative thesis research project with INIFAP were explored during the IARD 602-Mexico field course.
- February: The author was awarded a summer travel grant from the Latin American Studies Program to initiate thesis activities in Mexico.
- February to May: The author enrolled in System Dynamics Applications. Based on INIFAP feedback, thesis advisor recommendations, and author interest, the economic feasibility of value-added dairy products (aged cheeses) was selected for the development of a preliminary system dynamics model. The preliminary model was developed and initial baseline simulations were conducted.
- May: INIFAP extended an invitation for an introductory systems thinking and dynamic modeling course in Xalapa, Veracruz. Instructional materials were developed to integrate the course with parallel learning activities for the development of this thesis.
- June to September: The three-month introductory system dynamics course was taught for INIFAP in Xalapa, Veracruz. Group model

building exercises were integrated in response to INIFAP's request. Participants included INIFAP research and extension workers and a University of Veracruz student in economics.

- July: The author presented *Alternativas Económicas en Microcuencas de Montaña: Potencial del Queso Añejo de Cabra* at the International Workshop on Mountain Microwatershed Management in Xalapa.

2008

- January: The author worked as a field-learning facilitator in the IARD 602 course involving participatory rural appraisal workshops in two mountain communities, Cuatitlan and Xico Viejo, near Xico, Veracruz. After these workshops, follow-up activities from the introductory system dynamics course were completed with the INIFAP team.

From August 2007 to June 2008, the author also served as an informal advisor to Martín Alfonso López Rámirez, a student at the University of Veracruz in Xalapa for the system dynamics component of his undergraduate thesis in economics. This thesis, *Diversificación Productiva de Cafetales: Un análisis de riesgo y rentabilidad mediante la aplicación de Dinámica de Sistemas* (López Ramírez, 2008), was completed using the system dynamics methods taught in the introductory system dynamics course.

CHAPTER 1

INTRODUCTION

Mexico is a country of economic extremes. The wealthier northern states contrast with widespread poverty in southern states (Aguirre Reveles and Sandoval Terán, 2001). In the southern state of Veracruz, agriculture-based rural communities struggle with food insecurity, unemployment, and variable agricultural incomes. Market uncertainties often limit economic development opportunities in these rural communities. Poverty alleviation in these regions is contingent on improving food security and achieving rural economic growth (Blake, 2003). Specifically, an important component of poverty reduction is the generation of income opportunities for poor rural families. The generation of income opportunities can be achieved by producing high-value products with competitive advantages in local and regional markets. These products, especially when manufactured and marketed by local farmer collectives or cooperatives, have the potential to dramatically improve rural livelihoods through greater profitability from agriculture.

Multiple governmental and non-governmental organizations invest human and financial capital in poverty alleviation initiatives. There is a need to coordinate these efforts to improve the efficacy, impact, and potential for more widespread dissemination of successful interventions. This study aims to foster multi-institutional collaboration by implementing system dynamics methodology as a platform to encourage critical thinking, teamwork, information sharing, and improved policies in the analysis of complex, dynamic agricultural problems. To achieve this overall goal, group model building using system dynamics methods to conduct *ex ante* or preliminary assessment of these complex agricultural problems can be advantageous. Thus, the *ex ante* assessment of several problems encourages system dynamics learning, improves problem understanding, and ultimately improves decision making for agricultural research and development initiatives.

1.1 Collective Action for Value Addition and Marketing

To better capitalize on local and regional market potential and market access while reducing market uncertainty, collective action in the form of rural cooperatives could help increase household incomes. The production and marketing of higher-value products could help Veracruz highland communities generate additional income and become more active in dynamic local and regional markets. To achieve this outcome, cooperatives could play a facilitative role by involving local producers and increasing profits from value addition to products marketed by rural communities.

Small dairy cooperatives have had a positive impact on rural communities in various parts of the world. For example, in peri-urban locations of the Ethiopia highlands, the formation of small cooperatives called producer milk groups was successful in raising the incomes of rural dairy farmers (Nicholson et al., 1998). These cooperatives provided an alternative market outlet for fluid milk by purchasing it from farmers and processing it into dairy products such as cheese and butter. Some cooperatives further increased incomes of participating dairy farmers by returning profits in the form of dividends. They have also generated employment for members in rural communities.

In general the primary objective of these dairy cooperatives is to maximize cash flow to participating farmers, not necessarily to maximize profits (Nicholson et al., 1998). First, dairy cooperatives can purchase raw milk for a higher price than the local markets. By offering a higher price for raw milk, it is easier to encourage farmer participation. However, profits to the cooperative decrease and the risk of failure is higher, especially during the startup phase. Second, the dairy cooperatives can offer a lower price for raw milk, thereby accelerating solvency and increasing their ability to distribute profits with participating farmers. The profits from processing and sales of value-added products can be returned to farmers as dividends (Holloway et al., 1999). Due to the lower milk price, the initial benefits of farmer participation are less and the perceived risk of participation in the cooperatives is elevated, but the long-term cash flow to farmers may increase. Additional profits also allow for further marketing and cooperative capacity investments. A cooperative management strategy that includes a combination of both higher prices for raw milk and dividend payments could be especially advantageous for farmers.

Seasonal changes in milk production quantity and quality, and milk price and demand trends present a unique set of challenges for producers and cooperatives. In Honduras and Nicaragua, the quantity of milk produced is higher during the rainy season, but milk quality suffers and milk prices are lower (Holmann, 2001). In contrast, during the dry season milk supply decreases but milk quality is better from more hygienic milking with less muddy conditions. The superior milk quality combined with supply shortages render higher market prices.

Holloway et al. (1999) also suggested that the distance between market outlets and production points is highly correlated with milk quality due to lengthy delivery delays. Closer proximity to milk cooperatives decreases the distance to market, assuring fresh, higher quality raw milk for processing and increasing the attractiveness of farmer participation in milk groups due to lower transactions costs. Therefore, the location of the milk groups provides another benefit for dairy farmers by lowering these costs (Staal et al., 1997). In the Coatepec highlands, a value-added cooperative that processes and markets goat's milk could increase the profitability of smallholder goat production operations.

A successful dairy cooperative could provide considerable economic benefits to farmers while decreasing the time and resources they invest to market and sell raw milk. As a result, depending on the characteristics of the cooperative, market access can increase while sources of market uncertainty decrease.

1.2 *Ex ante* Problem Analysis

What is being referred to here as an *ex ante* problem analysis is commonly termed *ex ante* impact assessment in the field of international development. Many impact assessments are conducted *ex post* during the monitoring and evaluation phases of past projects. Although *ex post* assessments provide insight about what could have been improved, retrospective leverage points in the system, and reasons for desirable and undesirable outcomes, they cannot compensate for past shortcomings. In contrast, *ex ante* impact assessments evaluate problems, development programs, policies, and proposed solutions prior to their implementation.

These assessments provide insight about future development activities that can be used to improve planning, decision making, and methodology before the execution phase.

International development problems, especially those that address social systems in community development, are often poorly understood, and interventions have achieved mixed results. Even successful ones have unintended consequences. *Ex ante* impact assessments provide greater insight than expert intuition alone, thereby improving understanding in these complex systems (Sterman, 2006). There is great need for *ex ante* assessments to define leverage points, key variables, information needs, and critical conditions for the success of programs and problems. To develop an effective *ex ante* impact assessment, it is vital to attain a high level of understanding about the dynamically complex problem. This is especially critical in the often poorly understood, complex, multifaceted agriculture-based livelihoods of economically poor rural areas in developing countries (Thornton et al., 2003).

Kassa and Gibbon (2002) identified a common problem with the study of livelihood systems using the livelihoods approach as an “information overload.” They argue that an *ex ante* assessment using system dynamics modeling can help unravel the complexities of this information by concentrating on the system structure (the biophysical and information flows) and its relationship with the problematic behavior to facilitate “*ex ante* evaluations of alternatives.” By better understanding these systems and relating problem structure to behavior over time, development interventions could be improved. However, *ex ante* impact assessments are often limited by uncertainty because many input parameters are not well known and are characterized by multiple assumptions. Therefore, compared to more common *ex post* studies, *ex ante* assessments are typically less empirical.

Thornton et al. (2003) stated, "*Ex ante* studies can provide information to assist in the allocation of scarce research resources to activities that best match donors' development objectives" (p. 199). As a result, *ex ante* assessments are important to help ensure that scarce donor dollars are well invested to achieve increased long-term impact in international research and development initiatives. This is especially important since many international governmental and non-governmental organizations assess and implement projects in an *ad hoc* structural manner, quickly determining solutions from linear cause and effect mental models without fully considering the inherent feedback processes and the long-term implications of their actions (Nicholson, 2005). Although *ad hoc* methods can be helpful, they typically do not assure efficient resource use and can lead to unfavorable outcomes and policy resistance[1] in the long-term.

In order to make international research and development more effective, it is necessary to improve development planning mechanisms through the use of a combination of *ex ante* impact assessment tools. Thornton et al. (2003) suggest a mixture of quantitative and qualitative *ex ante* impact assessment methods with varying levels of participation by stakeholders depending on the assessment's purpose, available time, and available resources (funding and data). These methods include: village workshops, stakeholder and key informant interviews, formal surveys, economic analyses (e.g., econometric modeling), optimization models,

[1] Sterman (2000) defined policy resistance as a situation where "Policy results are delayed, diluted, or defeated by the unforeseen reactions of other people or nature. Many times best efforts to solve a problem actually make it worse."

community transects, spatial analysis (e.g., geographic information systems), market studies, anthropological or sociological studies, participatory technology development, simulation models, multiple objective mathematical models, and cost-benefit models.

One method for *ex ante* problem analysis is system dynamics modeling. As a stand-alone method, it can provide valuable insight into the dynamic behavior of a problem and its proposed solutions or policies. It can be even more effective when system dynamics methods are applied during participatory group model building initiatives that involve diverse stakeholders. System dynamics is valuable and insightful, but is even more useful when combined with other methods to more fully conduct *ex ante* impact assessments (Thornton et al., 2003).

1.3 Goals and Objectives

This study will address several questions related to system dynamics, problem assessment mechanisms in Mexico, and value addition and marketing cooperatives. These include:

- Is system dynamics modeling a potentially valuable tool for INIFAP programs?
- When combined with existing research and development methods, can system dynamics enhance INIFAP institutional capacity to conduct *ex ante* assessments of agricultural problems?
- Can interdisciplinary, multi-institutional collaboration facilitated by group model building contribute to INIFAP's objectives?
- Could the methods be applicable for other development organizations?

- What are the information needs, opportunities, and limitations to value-added or high-value agricultural production in the region?
- Is a dairy marketing cooperative a viable option to increase profits for rural farmers?

The goals and objectives are related to the author's overarching thesis goal, which is to build institutional capacity to conduct *ex ante* impact assessments using system dynamics methodology. The following objectives were established to answer the aforementioned questions:

Objectives

1. Help build professional institutional capacity for INIFAP researchers and extensionists through an introductory systems thinking and dynamic modeling course;
2. Develop an adaptable case study as an application of system dynamics modeling for the *ex ante* evaluation of options for agriculture value addition and income generation in the Coatepec highlands;
3. Foster multi-institutional and interdisciplinary collaboration through system dynamics group model building exercises to better understand the complexities of agricultural research and development initiatives.

This study also contributed to several goals in the TIES Mexico Initiative (Blake, 2003).

- Collaboratively address an array of complex development issues and challenges related to growth in demand for livestock products and changes in trade policies over the next two decades;

- Strengthen the capacity of Mexican partner institutions and Cornell University (and their broader constituencies) to conduct problem-solving research, instruction, and service, with the aim to identify and address the relevant development issues;
- Contribute to the preparation of a skilled cadre of interdisciplinary, systems-oriented agricultural researchers and extensionists that can address the needs of Mexico's livestock sector in the global marketplace.

1.4 Thesis Organization

This thesis combines system dynamics model development and policy analysis with the assessment of processes and methods for building professional capacity through interdisciplinary collaboration on complex agricultural problems. The thesis is organized into four chapters. First, the introduction provides the justification and need for the practical study. The remaining chapters are separated into two distinct but connected activities. The first activity is the introductory systems thinking and dynamic modeling course. The second is a case study of a system dynamics application to assess *ex ante* the economic feasibility of a value-added agricultural product in the Coatepec highlands.

The second chapter will explain the methods used in this study. Specifically, it will contain the structure and methods used in the introductory systems thinking and dynamic modeling course. It will also explain the system dynamics research process, and will provide a description of the model on value addition to goat milk by a rural marketing cooperative.

The results and discussion chapter will report and examine the results from the introductory course. Furthermore, policy analyses will evaluate different management options for a hypothetical value addition and marketing cooperative using the system dynamics model refined during the introductory course. The objective of the policy analysis is to evaluate the feasibility of the cooperative to improve the profitability of goat farming for rural farmers.

Chapter four will provide conclusions, recommendations, and lessons learned from the introductory system dynamics course and the model applied to a value-added cooperative for smallholders. Finally, the appendices contain the course outline for the introductory systems thinking and dynamic modeling course, model documentation for the value-added cooperative model, and brief evaluation of the model.

CHAPTER 2

METHODS

Many development-oriented organizations have invested in poverty alleviation programs in Veracruz. Multi-institutional collaboration and teamwork offer an opportunity to build capacity among development professionals, organizations, and rural community members. There are many methods to achieve successful partnership, exchanges, and development of critical skills. The methods used in this study were chosen to help foster an ongoing interdisciplinary, multi-institutional dialogue on rural development issues among the *Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias* (INIFAP), the *Universidad Veracruzana*, Cornell University, and other research and development actors in the region.

System dynamics training, problem conceptualization, problem modeling, and group model building are the primary methods used in this study. This chapter is organized into four parts: an introduction to system dynamics and group model building, the system dynamics research process, methods used in the introductory system dynamics course, and a description of the value-added cooperative model.

2.1 Introduction to System Dynamics

Systems thinking and dynamic modeling techniques have been widely used in various disciplines, especially in the business world. The applications have been used to assess problems for improving inventory management, increasing productive efficiency, and ultimately raising profit margins in economic applications. However, despite the potential benefits of system dynamics as an *ex ante* impact assessment tool, applications in agriculture and rural development have been limited (Nicholson, 2005). Considering the sometimes undesirable short-term and long-term results of rural development initiatives and the typical *ad hoc* approaches to solving complex agricultural problems, systems conceptual thinking and dynamic modeling provides a useful method to conduct *ex ante* assessments of these problems and programs. System dynamics is a feedback-based, problem conceptualization and modeling method that provides a useful framework for research and problem analysis. It can be used to improve the potentials of long-term policy decisions and development strategies.

One of the few explorations into agriculture and rural development applications using system dynamics was conducted by Nicholson (2005). He suggested that system dynamics modeling could be an effective mechanism for the assessment of complex problems in international rural development settings.

2.1.1 System Dynamics Modeling

The analytical method for *ex ante* impact assessment in this paper is systems conceptualization and simulation modeling using system dynamics methodology. The field of system dynamics was founded in the 1950s by Jay Forrester of the Massachusetts Institute of Technology (Ford, 1999). This methodology applies systems engineering concepts to interdisciplinary social, economic, and biophysical systems to improve solutions to real world problems (Nicholson, 2005; Sterman, 2000). A distinguished application that precipitated much debate was *The Limits to Growth* (Meadows et al., 1972). It reported predictions that world population and economic growth were unsustainable given a finite resource base, increases in pollution, and limits to global food production. The book was criticized due to the lack of documentation about the simulation model, an issue that was subsequently addressed in *Dynamics of Growth in a Finite World* (Meadows et al., 1974), which fully documented the model and its assumptions, parameters and equations. Since publication of *The Limits to Growth*, many system dynamics applications have been developed in multiple disciplines.

Kassa and Gibbon (2002) explained, "System dynamics modeling provides a set of tools to facilitate critical reflection on the articulation of problematic behavior in complex livelihood systems, and to enhance capacity to make *ex ante* impact assessments of alternative entry points to improve performance" (p. 1). Rather than focusing on the entire system, system dynamics engages a specific problem with defined limits that exhibits actual or hypothetical problematic behavior over time.

To assess the problematic behavior, system dynamics employs qualitative and quantitative methods to better understand complex problems (Maani, 2000). The qualitative methods comprise an array of conceptual tools that aid in understating the structure and behavior of complex problems. Examples of these conceptual tools are: graphs of the behavior of key variables over time (reference mode), causal loop diagrams, and stock-flow diagrams. Problem conceptualization also requires keen understanding about the problematic behavior. Consequently, a conceptual model facilitates critical thinking, comprehension, and effective decision making about the expected impacts from policy interventions on the problem. In many cases, the process of problem conceptualization and model development is more important to overall understanding and policy options than the specific case outcome *per se*.

System dynamics methods involve quantitative simulations comprising a network of stocks[2], their flows[3], and feedback processes (Nicholson, 2005). The manner in which these components interact depends on the decision rules[4] that define them. The simulation model is made up of two parts, the physical structure and the decision rules that govern the relationships among the variables specified in the physical structure (Sterman, 1991). Mathematically, system dynamics models are formulated as systems of ordinary differential equations that are continuously solved using numerical integration at a specified time step interval. This mathematical structure can quickly become overly complex. Fortunately, several software packages such as Vensim®, Stella®, Powersim©, and iThink® facilitate model development and simulation with dynamic models by providing an intuitive graphic interface to edit and manipulate variables, parameters, feedback loops, and equations.

2.1.2 System Dynamics Perspective

The system dynamics perspective or paradigm is often used to define system dynamics. Meadows and Robinson (1985) stated, "The primary assumption of the system dynamics paradigm is that the persistent dynamic tendencies of any complex social system arise from its internal causal structure" (p. 34). Alternatively stated, system dynamics modelers attempt to

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[2] Stocks accumulate material or information.
[3] Flows govern changes in stocks over time, and are defined by quantitative decision rules in rate equations.
[4] Decision rules are mathematical equations that govern variable interaction in system dynamics models.

explain problems based on their internal feedback structure instead of exogenous or random events that provide external shocks to the system. System dynamics methodology also focuses on dynamic complexity that reflects non-linear systems that change over time, are dependent on past events, governed by feedback processes, and that often exhibit counterintuitive behaviors (Sterman, 2000).

Additional elements of the system dynamics perspective include an emphasis on feedback processes instead of event-oriented linear conceptualization. Stocks and flows, explicitly described and often present in archetypal structures, typify many systems models. This methodology also focuses on general dynamic tendencies or patterns of behavior over time (e.g., exponential growth, exponential decay, oscillation) rather than point prediction. A system dynamics modeler would be more likely to note a continued oscillatory behavioral response pattern in milk price rather than in predicting the exact market price at a specific date.

System dynamics models depict continuous behavior over time rather than emphasizing discreet, non-continuous events. System dynamics permits the use of broad data and variable definitions (e.g., goals, perceptions, beliefs, and information flows), information that is often ignored in other disciplines. Inclusion of these “soft variables” is identified as both a strength and weakness of the method, as explained in the subsequent section. Finally, system dynamics focuses on specific problems where each model requires a well-defined purpose, model boundaries, and assumptions (Nicholson, 2005; Sterman, 2000).

Unlike other methods (e.g., econometric modeling), system dynamics does not require the assumption of equilibrium. Most models are fairly small aggregate representations of the real world, consisting of 10 to 200 variables. Thus, they are designed and best used to increase overall problem understanding and to improve the efficacy and accuracy of policy decision-making (Meadows and Robinson, 1985). Nicholson (2005), Sterman (2000), and Meadows and Robinson (1985) provide more complete descriptions of the system dynamics perspective.

2.1.3 Dynamic Modeling Critiques

Ex ante problem analysis has many limitations that depend on the model's purpose and the needs of stakeholders in the analytical exercise. A frequently cited issue is the high level of aggregation that characterizes system dynamics models along with the imposed limits or model boundaries[5]. In their general discussion of *ex ante* models, Antony and Anderson (1991) explained, "The underlying biological processes either became irrelevant or were oversimplified at high levels of aggregation" (p. 184). They suggested that such high levels of aggregation are usually insufficient for project-level analysis. However, the model evaluation and testing process includes tests of boundary adequacy and structure assessment, which help to determine if the amount of aggregation is appropriate for the model purpose.

Of course, it is impossible to include all variables in the entire system. Therefore, model boundaries must be specified based on the assessment's purpose (Thornton et al., 2003). Sterman (1991) noted, "For a model to be useful, it must address a specific problem and must simplify rather than

[5] In system dynamics modeling, boundaries are defined using an explicit boundary diagram comprising endogenous, exogenous, and excluded variables. System dynamics models often have wide boundaries that focus on endogenous factors, ignoring most detail complexity.

attempt to mirror in detail an entire system." Thus, useful models are a simplification of reality, addressing a specific problem within the broader system framework. Depiction of a system rather than a problem with defined boundaries would result in a model too complex to interpret, or to define its assumptions.

van Ittersum et al. (2007) acknowledged the importance of developing flexible generic models that encompass a greater variety of policy alternatives. A generic model is more easily replicable and adaptable for similar *ex ante* assessments. It could also be argued that quantitative simulation models are inherently subjective, based on the experience, knowledge, and resulting perceptions of the investigators. This criticism also applies to many classes of models.

System dynamics modelers are typically more open to the inclusion of "soft variables". "Soft variables" are those with limited available data or those that are difficult to measure or quantify (Sterman, 2000). Examples include goals, human behavior, perceptions, expectations, desires, quality, accumulation and flow of information, and parameters with limited data. This is an advantage of the system dynamics methodology because these factors are ignored by most modeling techniques and *ex ante* impact assessment methods (Sterman, 1991). Ignoring these factors implies they do not influence the system.

To identify and minimize sources of uncertainty and errors in depicting real world processes, extensive sensitivity testing and evaluation are important to an iterative model development process. System dynamics modelers consider model validation to be infeasible because all models are simplifications of reality. Validity can only be determined by its utility to model users and stakeholders (Sterman, 2000). Intensive testing helps assure usefulness. Twelve tests are established to evaluate structure, parameters, behavior, errors, and sensitivity of the model. Numerical, behavioral, and policy sensitivity tests can be conducted on a univariate or multivariate basis, and are used to measure model response to changes in assumptions. The ultimate robustness of a system dynamics model can be evaluated by responses to changes in assumptions, and more importantly by the utility of the model for end users.

2.1.4 Group Model Building

Group model building using system dynamics is widely used to increase stakeholder participation and understanding of complex problems. It encourages group learning, consensus building, and ownership of interventions during the development process and with its results (Vennix, 1994; Vennix 1996). Thornton (2004) indicated that all stakeholders must be "intimately involved" in the modeling process if the results are to be useful. Extensive stakeholder involvement helps ensure model utility by meeting stakeholder needs. Stakeholders include parties that are affected by or that make decisions concerning the specified problem.

Participatory model building with interdisciplinary teams enhances the final product with the distinct expertise, mental models, and opinions of the participants (Spang, 2007). However, extensive participation in the model development process can complicate the task. No standardized method has been developed to conduct group model-building workshops, and it has been identified as more of an art than a science, a problem leading to variable results (Anderson et al., 1997). The success of group model building workshops and courses often depends on the skill of the facilitator, interactions among participants, and the degree of uncertainty in specifying the problem.

Most group model building interventions are completed by an individual or small group of consultants or expert modelers who work together with a client stakeholder group to extract information about problem behavior (Anderson et al., 2007; Beall and Ford, 2007; Luna-Reyes et al., 2006; Vennix, 1999; Anderson et al., 1997; Richardson and Anderson, 1995). These strategic interventions are often solicited by clients on a contractual basis. Behavior over time and pieces of stock-flow or feedback structure are proposed and explained to attain consensus among the stakeholder group. The process often begins with several small models called concept models (Richardson, 2006). These easily understandable models are based on preliminary research and information provided by the client. They are used to facilitate initial understanding of system dynamics and to begin gathering more precise information. The modelers later return to the client group with a conceptual model or a simulation model that permits policy analysis for stakeholder decision support.

During the modeling intervention process, the consultants facilitate the information elicitation process using different scripts, participatory exercises to extract information (e.g., problem description, key variables, reference mode behavior, system structure, and parameter estimates from stakeholders) and build model structure (Anderson and Richardson, 1997). An experienced modeler works simultaneously to construct conceptual models and possibly simulation models based on consensus information gathered from the stakeholder group. This form of group model building can be quite effective but does not normally build stakeholder capacity to learn systems thinking and dynamic modeling techniques in order to construct models on their own.

Different from more typical group model building interventions, the participatory group and team model building activities and exercises in this study are part of intensive study of systems conceptualizations and system dynamics modeling during the short course. The participants are also the modelers in course exercises. Thus, the group model building activities are designed to increase methodological comprehension while completing *ex ante* assessments to increase understanding and build consensus about specific problems. This “learning by doing” approach favors and compliments the analytical and computational skill set of the course participants, and importantly, their subject matter expertise about the selected problems.

The course involved participatory group and small team model building exercises. For example, a preliminary model, which addresses a selected agricultural development problem for organizational stakeholders, facilitates system dynamics studies. Teams of three also completed initial steps of the modeling process for other agricultural development-related problems during the course. The author acted as a facilitator of development of the conceptual model and simulation model.

2.1.5 Quantitative Versus Qualitative System Dynamics

Group exercises are used to develop conceptual models and simulation models. Participants prefer a quick and direct path to problem solutions rather than systematic completion of the modeling process (Stave, 2002). Similarly, although participants may prefer a quantified simulation model at the conclusion of the workshop, Vennix (1999) suggested that simulations need not be the only objective. At times it is neither useful nor feasible to complete the entire model-building process (Vennix, 1999). Thus, successful group exercises have focused only on the qualitative model-development process (Siemer and Otto, 2005). Quantification can either increase the understanding of a problem or be misleading, resulting in questionable policy decisions (Coyle, 1999).

In contrast, to obtain further insight about the problem through simulation it is desirable to quantify a simulation model during a group model building exercise. Furthermore, quantification can reveal behavioral responses that are nearly impossible to infer from complex conceptual feedback structure alone (Sterman, 2000).

The decision to quantify a model depends on a number of factors including available time, facilitator expertise, participants' background, group size, group expertise, problem characteristics, and stage of preliminary model development (Vennix, 1996). If system dynamics is determined to be appropriate method for the selected problem, any one of these factors can be the most limiting in the model-building process, and in deciding if quantification is feasible.

2.1.6 System Dynamics Modeling/Research Process

The system dynamics modeling process is used to conduct the *ex ante* problem analysis in this project paper. The iterative modeling process consists of five phases (Sterman, 2000), which should be used to evaluate a problem and analyze possible solutions. In this case, it is used as an *ex ante* problem and policy analysis mechanism for INIFAP.

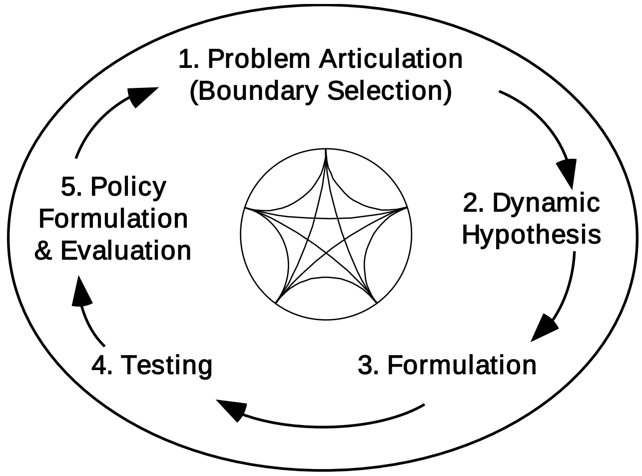

Figure 2.1 The system dynamics modeling process is an iterative feedback loop. The completion of each phase can result in the modification of previous phases (Sterman, 2000).

1) **Problem articulation** explains the background of the problem, the modeling exercise's purpose, and problem evolution via a historic or hypothetical reference behavioral mode[6] that is represented in a behavior-over-time graph. This provides a working explanation of the evolution of the problem.

2) The **Dynamic Hypothesis** is a conceptual model typically consisting of a causal loop diagram, stock-flow diagram, or their combination. The dynamic hypothesis seeks to define the critical feedback loops that drive the system's behavior. When quantified in a simulation model, the endogenous feedback structure of a conceptual model should be capable of reproducing the reference behavioral mode based on the assertion that "structure causes behavior."

[6] The reference mode is a graph or series of graphs that describe the evolution of a problem over time.

3) The **formulation of a simulation model** is the transformation of the conceptual model into explicit stock-flow structure. The model is quantified (assigned parameter values and equations) so that simulations can be conducted.

4) **Model testing**, or evaluation, consists of a series of tests to evaluate the model's robustness. Typically, comprehensive evaluation unveils errors that cause one to return to previous phases in the iterative modeling process. Sensitivity testing is also conducted here to evaluate structure and variables with high uncertainty. Numerical, behavioral and policy sensitivities to changes in parameters and structure are evaluated relative to the model's purpose.

5) **Policy Formulation and Evaluation**: Policy formulation and evaluation often determines if the model is useful for the specified purpose. In this phase, model users test policy options, interventions, or actions to improve understanding about potential short-term and long-term results, unintended consequences, and sources of policy resistance. This should lead to improved decision making.

2.2 Professional Short Course on System Dynamics

The systems thinking and dynamic modeling course offered to INIFAP *Campo Experimental* personnel was conducted from June to September 2007. The course was developed in response to INIFAP's desire to improve their programs, promote multi-institutional and interdisciplinary collaboration, and to add an *ex ante* dynamic conceptualization and simulation method to their repertoire of technology and development mechanisms. The overall goal was to build institutional capacity in *ex ante* impact assessment using system dynamics methods and tools. The objectives for the short course were designed to complement and enhance INIFAP goals.

2.2.1 Course Objectives

Participants will:

1) Learn the basics of systems thinking and dynamic modeling;
2) Increase knowledge about basic techniques for the *ex ante* assessment of complex agricultural problems using system dynamics methods;
3) Complete group model building exercises to analyze and evaluate the feasibility of dairy cooperatives to increase net economic returns in highland communities, thereby building confidence in the value-added cooperative model (Section 2.3);
4) Use system dynamics methods to model other problems for *ex ante* decision support to improve project design, to identify information needs, and to better serve INIFAP clients in mountain communities of Veracruz.

2.2.2 Course Location

The course was held at INIFAP's *Campo Experimental* offices in Xalapa, Veracruz. The offices are located in the *Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación* (SAGARPA) facilities. Three field trips to the rural community of Micoxtla supported team learning and group model-building exercises.

2.2.3 Course Equipment, Supplies and Learning Materials

Equipment and supplies were provided by INIFAP. These included laptop and desktop personal computers, an LCD projector, a white board, and markers. Transportation for field trips was also provided by INIFAP. Vensim® PLE software by Ventana Systems, Inc. was used to carry out modeling exercises. Supporting literature (Appendix 1) and the course design were assembled and developed by the author as described in Section 2.2.5.

2.2.4 Course Participants

There were eight consistent participants throughout the short course. A total of sixteen participants attended at least one session. Seven of the eight consistent participants were members of the multidisciplinary team stationed at the Xalapa offices of INIFAP's Campo Experimental. Among the seven INIFAP participants, three were computer systems specialists that worked primarily with GIS applications, statistical analysis, and various other software applications. Three INIFAP participants were members of the micro-watershed development team with specific training in agronomy, agricultural science, and social science. The final INIFAP participant was an agronomist and the director of the Campo Experimental at Teocelo. One additional participant was a student in the School of Economics at the University of Veracruz in Xalapa.

2.2.5 Course Structure

The short course was structured based on the Applied Economics and Management (AEM) 494 "Introduction to System Dynamics Modeling" and AEM 700 "System Dynamics Applications" courses taught by Dr. Charles

Nicholson at Cornell University. A previous short course titled “Application of System Dynamics to Agricultural Settings in the Gulf Region of Mexico” was also used as a general guideline for lectures, materials, and exercises (http://tiesmexico.cals.cornell.edu/courses/shortcourse5/). The previous short course was taught by Dr. Charles Nicholson in 2005 at the *Universidad Veracruzana* in Veracruz Port.

The course consisted of three components: introductory system dynamics coursework, group model building exercises related to value addition to goat’s milk, and small team model-building exercises for selected problems. The three components were complementary, providing both theoretical and practical learning opportunities for course participants. First, theoretical course materials were presented weekly in two or three two-hour sessions. Practical exercises complemented the theoretical lectures. The course session outline in Appendix 1 includes the final two-day workshop and supporting literature. The final workshop was designed to review materials covered during the course, to address additional topics in response to participant feedback, and to define future strategies for potential system dynamics applications by the INIFAP team.

Second, a case study of the economic feasibility of value addition to goat’s milk and the marketing of cheese made from it by a hypothetical rural dairy cooperative was a core component of the course. The *ex ante* assessment was designed to determine if aged goat cheese could be a feasible economic alternative for farmers in Micoxtla. This group model-building component was completed using a preliminary version of a system dynamics model developed by the author (Section 2.3). The objectives of INIFAP participation in the model building process were to facilitate group learning, to evaluate the preliminary model, and to generate confidence in future model specifications. Course participants first examined and evaluated the preliminary simulation model as a participatory learning mechanism. The expert subject matter knowledge and direct observations provided by INIFAP researchers and technicians helped to improve the accuracy of the case study and of the model. This participation also assured that the simulation model could be a useful resource for learning system dynamics, and a useful policy analysis mechanism for the *ex ante* evaluation of cheese cooperative management.

The case study, described in Section 2.3, was completed using the system dynamics modeling process (Section 2.1.5). Importantly, it illustrated problem conceptualization and simulation model formulation as an *ex ante* impact assessment mechanism for agriculture and rural development.

Third, small teams initiated their own analytical modeling processes focusing on specific problems related to their research interests and own experiences. Course participants were divided into three teams of similar interests, experiences, and roles in INIFAP. Teams were instructed to select an appropriate dynamic problem of interest to the INIFAP *Campo Experimental*. After problem selection, the teams completed the initial steps of the system dynamics modeling process. They focused primarily on the initial qualitative phases of the modeling process, also developing incipient simulation models. Each team presented its model development progress on three occasions during the course. These presentations provided an opportunity for detailed discussion by multi-disciplinary INIFAP faculty. The first presentation described the selected problems. The second presentation conceptualized the problem and represented the dynamic hypothesis for the modeling process. The third presentation explained the results of an initial attempt to formulate a simulation model. Each of the three presentations was cumulative, but required revision of the previous phases based on facilitator, participant, and non-participant feedback both during and after the presentations. This informal INIFAP supervisor and peer review process enriched group thinking and improved future iterations in the modeling process for all teams. Therefore, team model development was an iterative learning process benefitting all course participants.

2.3 Value-Added Cooperative Model

The value-added cooperative model was designed with INIFAP as an adaptable policy analysis tool for the assessment of value-addition to agricultural products. The dynamic biophysical and socioeconomic model represents the aggregate caprine resources in Micoxtla and a rural value addition and marketing cooperative. The model consists of nine components: 1) community goat flock, 2) forage resources, 3) milk allocations, 4) cooperative cheese production, 5) cooperative productive capacity, 6) cooperative management and decisions, 7) aged cheese market, 8) producer profitability expectations, and 9) user interface. The ensuing description summarizes the background, problem conceptualization, and structure of the simulation model.

2.3.0.1 Model History

An *ex ante* assessment of the economic feasibility of goat cheese production in the Veracruz highlands was initiated in 2007 in the introductory system dynamics course at Cornell University. The resulting problem analysis and preliminary simulation model were used to illustrate and teach the short course (Section 2.2) to INIFAP researchers and extension workers. The preliminary model was employed in group model building exercises to improve understanding of the modeling process. Course participants also contributed expert viewpoints for model improvement during sensitivity testing and model evaluation exercises. Finally, participants conducted some policy analysis using the model's user interface.

2.3.0.2 Micoxtla Community Background

Micoxtla is a small highland community located in the municipality of Xico, Veracruz, Mexico at an altitude of 2,040 meters on the eastern slopes of Cofre de Perote mountain in the Sierra Madre Oriental mountain range. The approximate geographic coordinates are 19° 27' N and 97° 2' W. The population of this rural community is about 260 people. The community is situated in the Coatepec micro-watershed, one of three action areas for INIFAP's micro-watershed development programs.

Agricultural production consists of two staple crops, maize and beans, as well as potatoes, forages, and patio vegetable production (INIFAP, 2006b). Most households also raise goats and chickens. Only a few families raise hogs, cattle, and sheep. The majority of agricultural land lies on steep slopes where soil erosion is a chronic problem. Families cultivate an average of 2.3 hectares. Four-hundred and sixty-six hectares of private and communal agricultural, pasture, and forest land delimit Micoxtla. Most agricultural activities are for household consumption. INIFAP has been collaborating with the community since 2003 on various community and agricultural development activities. Their work is now undergoing a transition into micro-watershed investigation and water conservation.

According to Díaz Padilla (personal communication, July 5, 2007), a Micoxtla family must earn an average of $5,500 pesos per month (U.S. $550 at an exchange rate of $10 pesos per dollar) to comfortably sustain their livelihoods. If families do not reach this income benchmark, the presumed likelihood of emigration from the rural community is greatly increased. One of INIFAP's primary objectives is to help Micoxtla families surpass this benchmark.

2.3.0.3 Micoxtla Economic Activities

The majority of Micoxtla's inhabitants work primarily in agricultural production, although some individuals travel to the surrounding cities of Xico, Coatepec, and Xalapa where employment opportunities are more plentiful. In addition, many community members seasonally migrate to nearby coffee plantations in the Teocelo region to harvest coffee. INIFAP (2006b) found that most Micoxtla families struggle with seasonal food insecurity and economic instability. The principal products sold are milk, young goats for meat (*cabrito*), and eggs after fulfilling household consumption needs (INIFAP, 2006b). Nearby Xico (five kilometers), a tourist destination, provides a ready market outlet. Larger population centers and markets are also located in Coatepec (12 km) and Xalapa (25 km).

An array of traditional products is produced in Micoxtla and could allow community members to compete in higher-value local and regional markets. According to Ramírez-Farías (2001), one effective way to compete in these markets is to produce differentiated products based on consumer demand and product acceptance.

2.3.1 Problem Description

An important source of income for Micoxtla families is the sales of caprine products: milk and meat (*cabrito*). However, production is low and net income is modest. Currently, most milk is sold directly to a local milk processing plant at 3.5 to 4.5 pesos[7] per kg, varying seasonally (INIFAP, 2006b). Micoxtla family members walk up to ten kilometers per day to sell as little as one kg of milk, which indicates the importance of this cash income. Aged, or premium, cheese production in Micoxtla could provide an opportunity to increase household earnings from dairy products, an idea originating in the community itself. Milk that is not sold is either consumed in the household or used to produce traditional fresh cheese. Similar to raw milk, this cheese product adds little value and its profitability is low.

Micoxtla community members identified the low earnings from goat's milk as a processing and marketing problem stating, "We don't know how to prepare higher quality cheeses and don't have a place to sell them" (INIFAP, 2006b). Micoxtla farmers have expressed an interest in learning to produce and sell new types of cheese with the objective of increasing profits from goat's milk and improving household economic conditions. Consequently, among the numerous options to generate additional income in Micoxtla, this strategy was chosen for this collaboration. Therefore, *ex ante* assessment of the feasibility of value-added goat's milk production, processing, and

[7] The exchange rate in 2008 was approximately ten Mexican pesos per one U.S. dollar.

marketing by the hypothetical dairy cooperative was undertaken as a project study and as a mechanism for the application of system dynamics principles in response to community initiative. In addition to milk, *cabrito* production and sales were also considered.

2.3.1.1 Reference Mode

The reference mode graph (Figure 2.2) illustrating monthly profitability from aggregate community goat operations includes income from culled animals, *cabrito*, fluid milk sales in Xico, fluid milk sold to the cheese cooperative, and dividends paid by the cooperative. To compute profits, animal production costs, forage production costs, and milk production and marketing costs are subtracted from income.

Although historical data are unavailable, producer perceptions suggest that profits from goat enterprises are low and uniform in the region. Seasonal fluctuations in profit are influenced by seasonal rainfall and forage supply and milk price instability. By adapting milk processing to include higher-value aged cheese, profits could increase. The target market is the growing tourism industry in the region, especially in the nearby town of Xico. A time horizon[8] of 20 years was chosen to assess future patterns of behavior after initiating aged cheese cooperative operations. The 20-year time horizon is sufficient to capture major changes (e.g., collapse) in profits from limiting factors such as forage and market instability.

[8] The time horizon is the past and future time necessary to describe the historic and hypothesized behavior of the problem.

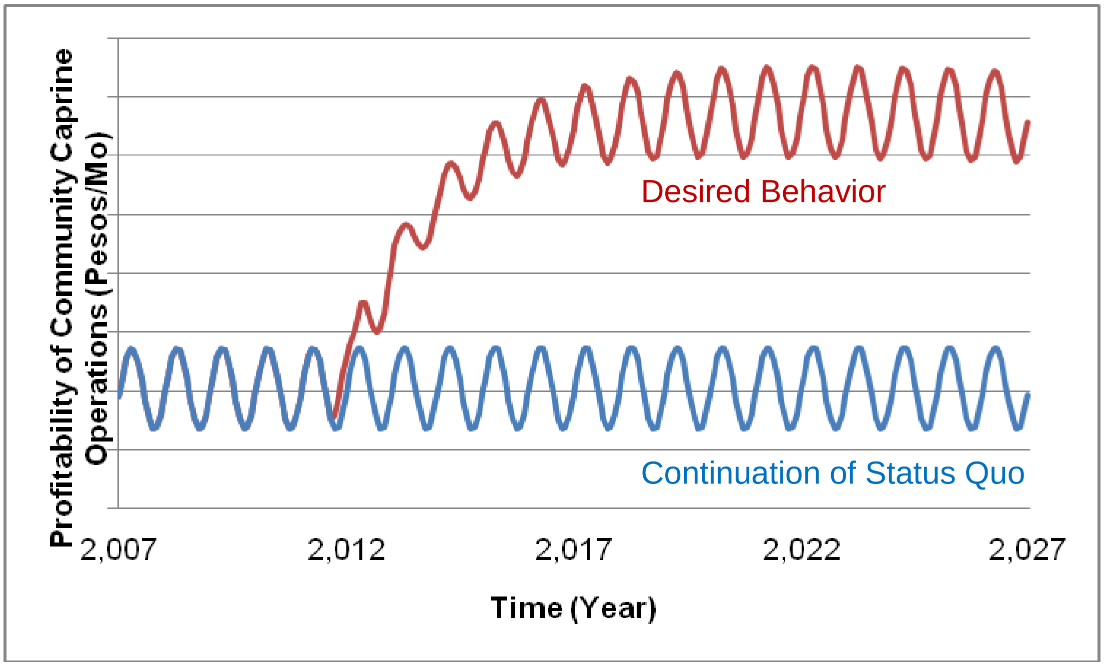

Figure 2.2 Reference Mode: Monthly Profitability of Aggregate Community Caprine Operations. Desired future behavior and continuation of the *status quo* are shown.

The reference behavioral mode (Figure 2.2) indicates the continuation of the *status quo*, ongoing low profits from community goat operations. The *status quo* behavioral pattern is yearly seasonal oscillation, which is sustained over time. The desired future behavior is to increase profits from the flock as additional income is received from cooperative raw milk sales and dividend receipts. The desired behavioral mode is goal seeking with yearly seasonal oscillations. Aggregate community profits from goat enterprises might not be the best indicator of household well-being, but it is an important indicator of goat production's contribution to community household economic well-being. Other indicators of ultimate well-being (e.g., food security, nutrition, and health) could be considered, but are outside the boundary of this study.

2.3.1.2 Model Purpose

The purpose of this *ex ante* impact assessment was to improve INIFAP's understanding of the opportunities and associated factors limiting higher-value commodity production. The model was used to analyze management scenarios for a hypothetical rural dairy cooperative, which holds as its primary objective increased profitability of goat farming. If fruitful, the modeling exercise would enable INIFAP to better design and execute a development interventions related to value-added production, marketing, and cooperative management. As the primary stakeholder in this case study, the INIFAP team has been involved extensively in its development and revision during group model building exercises. Other stakeholders include Micoxtla farmers, local municipal government, competitors, and milk and cheese buyers.

INIFAP's caprine production objective is to increase the incomes of Micoxtla families. The methods to achieve this objective are primarily through improved management to increase the quantity and quality of milk produced. Examples include improved management of pastures, nutrition, animals, sanitation, and shelters. The impact of these management interventions may be important but does not focus directly on improving the profitability of community caprine operations. Therefore, the investigation and development of milk and premium cheese markets and the feasibility of a producers' cheese cooperative to achieve the overall objective are analyzed in Section 3.2 to assess their impact on farmer incomes.

2.3.2 Model Conceptualization

The development of a conceptual model using system dynamics methods typically employs causal loop diagrams and stock-flow diagrams. A causal loop diagram consists of a set of feedbacks that collectively define the structure of the system, which is hypothesized to generate its behavior (Sterman, 2000). The conceptual diagram is a structural hypothesis to explain the behavioral reference mode. There are two classes of feedback loops. Positive or reinforcing loops typically stimulate growth whereas negative or balancing loops slow growth, producing oscillation when delays[9] are present.

2.3.2.1 Model Feedback Structure

There are several key feedback pathways for the five income generation activities associated with goat production in Micoxtla (Figure 2.3). These activities include milk sales in Xico, cooperative milk sales, cooperative dividend payments, sales of culled animals, and male kid (*cabrito*) sales. Each activity creates a positive or reinforcing feedback loop leading to system growth in the absence of limitations. The only negative or balancing feedback loop in the production side is forage supply. Additional balancing feedback processes are found on the market side. More detailed feedbacks have been omitted for simplicity.

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[9] In causal loop diagrams, a delay process is represented by two perpendicular lines in a causal link.

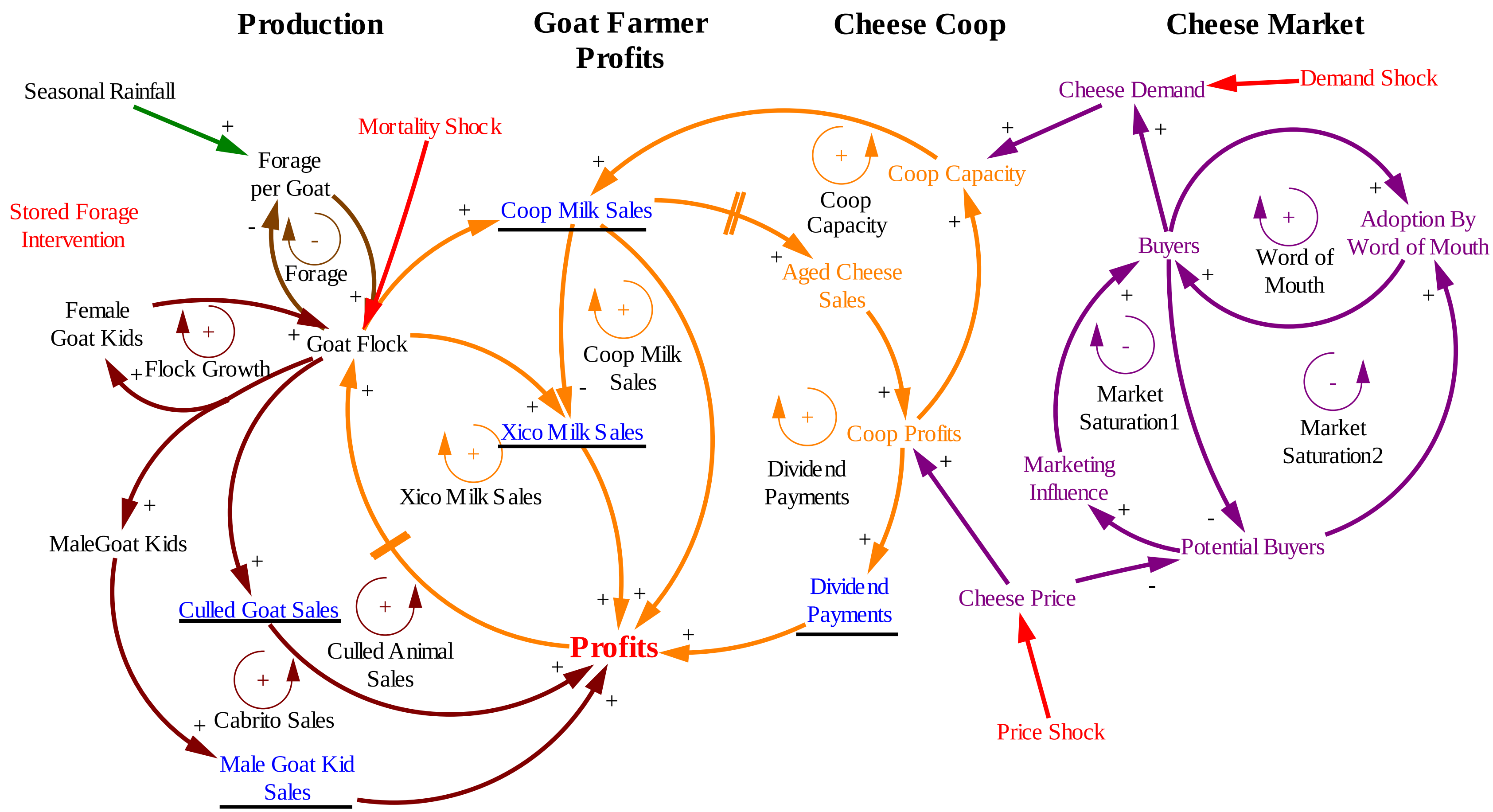

Figure 2.3 The simplified conceptual causal-loop diagram displays the sources of producer income generation from caprine operations as underlined variables. The basic feedback structure of the goat flock, cheese cooperative, and the cheese market are shown. The network of feedback structure is hypothesized to cause the behavior over time depicted in the reference mode.

The historic and undesired pattern of future behavior in the behavioral reference mode (Figure 2.2) is explained by dynamic equilibrium[10] in all stocks except those in the cheese cooperative and cheese market components of the model, which are inactive and in static equilibrium[11]. The market structure (Figure 2.3) is activated by initial marketing of value-added product, which then initializes cheese cooperative operations. This includes the cooperative milk sales, dividend payments, and capacity feedback loops.

The market, although it is exogenous to the rest of the model in the conceptual diagram, contains additional balancing feedback loops that limit system growth. Goal seeking or capacity seeking behavior is driven by multiple feedbacks. Constraints that contribute to goal seeking behavior in the profitability of goat operations include milk production capacity, cheese production capacity, seasonal forage production costs, dividend payments, sales of *cabrito* and culled animals, and overall flock profitability. Farmer perceptions, desires, and cost limitations have been omitted, but they also collectively play a role in defining the goal seeking capacity limit. Nonlinear dynamics permit feedback loop and capacity dominance to shift during a simulation, thereby affecting observed behavioral patterns.

Specifically, increases in the profitability of community caprine operations are inferred from the dividend payments feedback loop. Market size and cheese production capacity generate the initial capacity constraint. After the initial market expansion occurs and cheese production capacity

[10] Dynamic equilibrium occurs when the inflows to each stock are equal to the outflows. Consequently, the stock values do not change over time.
[11] A stock is in static equilibrium when all inflows and outflows are inactive or equal to zero.

investments are fulfilled, milk supply and market capacities shift seasonally, thus determining the capacity for value-added product production and sales.

2.3.3 Simulation Model Description

The simulation model represents the community caprine resources in Micoxtla. Twenty-five families own approximately 300 goats (INIFAP, 2006b). Flock management is carried out at the household level. Families allow their individual flocks to graze several hours per day on Micoxtla's communal pasture and forest lands. Families also cut and carry forages, such as forage oats and rye grass, to feed animals when they are enclosed in corrals and sheds. Some families seasonally supplement with cracked maize and minerals to support animal health.

Despite apparent complexity, most biophysical relationships and decision rules are straightforward and aggregated. Consequently, the adaptable model depicts the primary interactions and constraints to the economic success of value-added cheese production for a rural cooperative.

2.3.3.1 Reference Mode Accounting

Three caprine enterprises are considered in the reference mode. First, in the flock enterprise, culled does are sold at a nominal price ($300 pesos/doe). In addition, young bucks (*cabritos*) are sold in Xico to make a traditional Mexican dish ($300 pesos/*cabrito*). The flock enterprise is charged for non-feed animal costs at a constant monthly rate ($5 pesos / (goat * month)). The second enterprise is fluid milk production and sales. Milk can either be sold in Xico (Equation 16) or to the cooperative (Equation 15). This farm level enterprise is charged a fee of two pesos per kg for milk marketing and transport. The community caprine operation can also receive income from the cheese cooperative as dividend payments (Section 2.3.3.2.7). The entire goat operation is charged for forage production costs (Section 2.3.3.2.2). The behavioral reference mode, monthly profitability of community caprine operations, represents the profitability of the community flock, rather than the outcomes for an individual farm household (Figure 2.2). When the community enterprise is profitable, farmers reinvest in the flock by purchasing adult does (Section 2.3.3.2.1).

The third enterprise, the aged cheese cooperative (Sections 2.3.3.2.4 to 2.3.3.2.7), is independent of animal production and milk sales. The cooperative buys fluid milk from farmers and incurs expenses for cheese production, storage, and marketing. The cooperative's profits are invested in productive capacity or redistributed to participating farmers as dividend payments.

2.3.3.2 Model Components

The simulation model consists of nine components: the aggregate community goat flock, forage resources, milk allocations, cooperative aged cheese processing, aged cheese market, cooperative productive capacity, cooperative cash flow and decisions, farmer profitability expectations, and an interactive user interface. When seasonal rainfall patterns and seasonal milk price oscillations are not exogenously imposed, the model initializes in dynamic equilibrium. Dynamic equilibrium is achieved because the inflows and outflows from each stock are equal and stocks are unchanged. All nonlinear table functions[12] are normalized to assure dynamic equilibrium except for the aged cheese cooperative and market components, which initialize in static equilibrium because the cooperative is not processing milk at the outset. In addition, some initial values for stocks and parameters are selected for dynamic equilibrium. A description of the assumptions, boundary, and parameters of the model is included in Appendix 2. The simulation model was formulated in Spanish to facilitate use by the INIFAP team.

2.3.3.2.1 Community Goat Flock

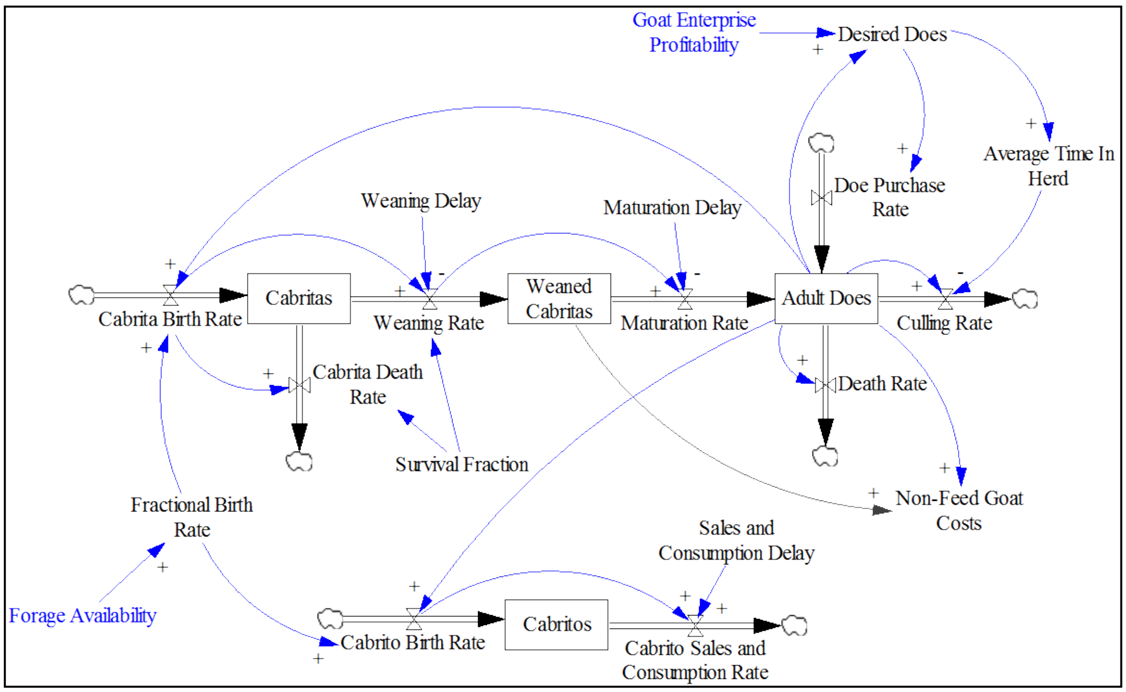

Figure 2.4 Simplified Goat Flock Stock-Flow Structure. The community goat flock structure is organized into four stocks to represent flock management. *Cabritos* and *cabritas* are young male and female goats, respectively.

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[12] Table functions, also called lookup functions, normally use a proportion of a variable to its reference value to compute its effect on another variable. To initialize a model in dynamic equilibrium, the proportion is equal to one, which does not affect the default or reference value for the affected variable.

The stock-flow structure of the goat production component of the model consists of a doe aging chain divided into three stocks: c*abritas* (young does)*,* weaned c*abritas,* and adult does. An additional stock of c*abritos* (young bucks) is also part of the goat production stock-flow structure but is not included in the aging chain because all young male goats are either sold or consumed locally. These four stocks constitute the goat flock. The fractional kidding rate (Equation 1) is a function of the birthing interval, the number of kids per parturition, and the number of adult does. This fractional rate varies based on the fulfillment of required forage needs through a reference multiplicative formulation[13]. The fractional kidding rate is uniformly distributed so that 50 percent of the kids are males and 50 percent are females.

(1) Fractional kidding rate = (kids per parturition / birthing interval) * effect of forage availability on fractional kidding rate(fraction of forage needs met)

This simple kidding formulation could be compared to or revised based on the more complex productivity index proposed by Bosman et al. (1997). The Bosman index measures performance at the individual animal-level. It also considers the age at first parturition, the age at subsequent parturitions, and the live weight of the litter at weaning. Therefore, doe productivity is measured in live weight per year rather than as a simple fractional kidding rate.

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[13] The reference multiplicative effect is a common system dynamics formulation that multiplies a variable's reference value by a nonlinear effect that is dependent on an additional variable or variables. The nonlinear effect is often normalized to return the reference value under initial, known, or default conditions. The effect uses a lookup function.

The c*abrita* stock is affected by one inflow, the *cabrita* kidding rate, and two outflows, the death and weaning rates. The weaning rate, an intermediate flow between the c*abritas* and weaned *cabritas* stocks, is a third-order delay of the *cabrita* kidding rate and depends on the constant average weaning age. The weaned *cabritas* stock has only one outflow, a high-order (eighth) delay in the weaning rate. The combined weaning and maturation delays form a higher-order delay distribution around the total average delay time for doe maturation. *Cabritas* must reach their first parturition (kidding) to complete maturation to adulthood, which is represented by entry into the stock of adult does. The age at first parturition is slightly over two years (G. P. Alvarez Montes de Oca, personal communication, August 16, 2007). It is assumed that all adult does produce milk.

The stock of adult does has an additional inflow, purchased animals, and two first-order outflows, the rates of culling and mortality. It is assumed that Micoxtla producers make decisions about flock composition based on the profitability of the enterprise. The culling rate (Equation 4) changes with average time in the flock, a variable that changes as a function of the ratio of desired adult does to actual does (through a reference multiplicative formulation). When the desired number of adult does exceeds the actual number of adults, does are purchased (Equation 5) and the culling rate decreases (Equations 3 and 4). The desired adult does variable (Equation 2) is defined by a reference multiplicative formulation that adjusts based on the actual number of adult does and expected profitability of the goat operation. Does can be purchased when sufficient cash is available and the desired number exceeds the actual count of adults. The desired does and doe purchase formulations were adapted from the production capacity formulation in Sterman (2000).

(2) Desired does = adult does * effect of profitability on desired does (ZIDZ((expected profitability-reference profitability), reference profitability))[14]

(3) Average time in flock = MAX (base average time in flock * effect of ratio of desired adult does to adult does on average time in flock (ZIDZ(desired adult does, adult does)), minimum time in flock)[15]

(4) Culling rate = adult does/average time in flock

(5) Doe purchase rate = MAX ((MIN (purchases permitted based on available cash, (desired adult does – adult does) / desired adult does adjustment time)), 0)

The adult doe mortality rate is determined by the fractional mortality rate. This is a function of several parameters so that the model initializes in dynamic equilibrium. The fractional rate is also allowed to vary according to forage availability via a reference multiplicative formulation.

It is assumed that all culls can be sold at a fixed price and that all animals in the stock of adults incur monthly non-feed costs. Therefore, sales of culled animals and monthly non-feed costs affect the monthly profitability of the aggregated community caprine operation.

The *cabritos* stock is affected by the fractional kidding rate inflow and goat sales and consumption outflow. The outflow is a third order delay of the inflow. It is assumed that all *cabritos* are either sold or used for household

[14] ZIDZ means "zero if divided by zero." When that the denominator is equal to zero, the function returns a value of zero instead of producing a floating point error due to division by zero (Ventana Systems, Inc., 2008). (e.g., ZIDZ(10,0) = 0)

[15] The MAX function returns the higher of two possible values (Ventana Systems, Inc. 2008). (e.g., MAX (4,7) = 7)

consumption, and all that are not consumed are sold. *Cabrito* sales revenues are determined by the number of animals sold and a constant *cabrito* price. All kids in the stocks of *cabritos* and *cabritas* consume milk.

Adult males are not modeled explicitly because most Micoxtla producers do not maintain breeding bucks. The few producers that do own breeding bucks lend them to other producers, which sometimes incurs small breeding fees that were ignored and excluded from the model boundary (INIFAP, 2006b).

2.3.3.2.2 Forage Resources

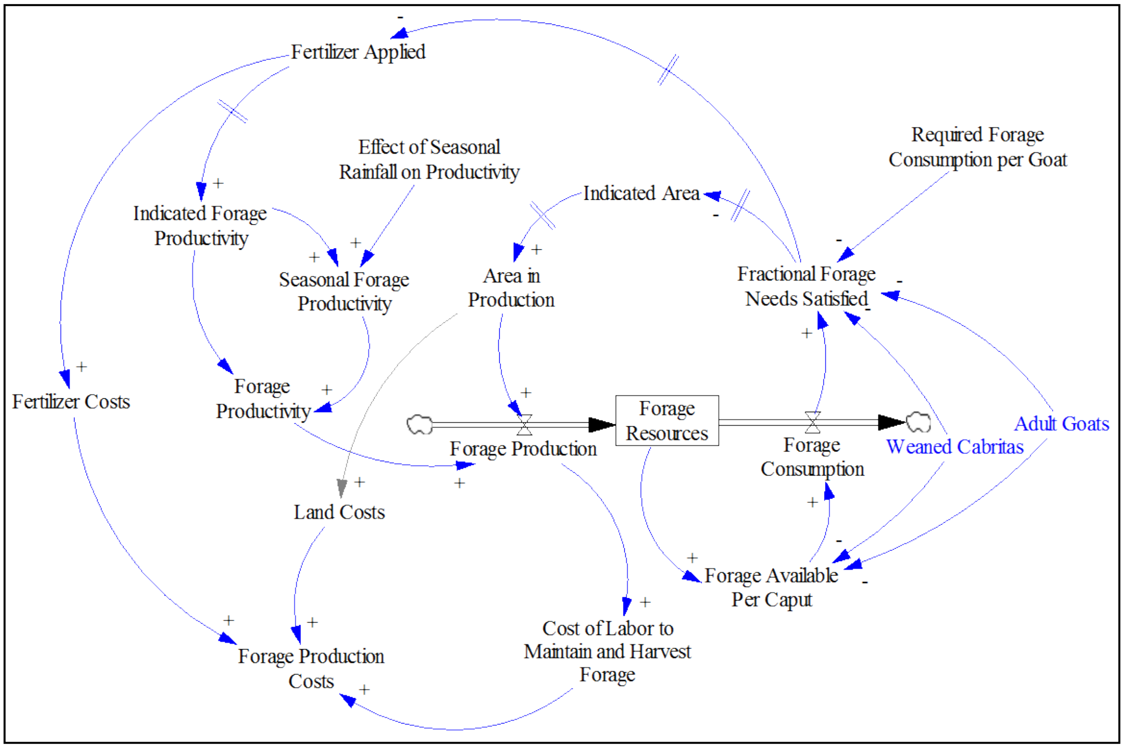

Figure 2.5 Simplified forage stock-flow structure. Multiple balancing feedback loops regulate forage production and consumption based on forage availability. Rainfall directly affects forage productivity.

The animal aging chain is connected to the forage resources component through the forage available per caput (Equation 6) and fractional forage needs satisfied (Equation 7). The ratio of available forage to reference forage per goat defines the fraction of forage needs that are met (Equations 6 and 7). This fractional forage condition nonlinearly affects the kidding rate, adult goat mortality, milk production, and desired forage resources via their respective reference multiplicative effect formulations in other model components. This forage resources formulation does not account for forage quality. Bosman et al. (1997) proposed equations that could be adapted to represent forage quality and animal maintenance requirements. They simulated animal productivity in response to changes in several parameters such as feed intake, feed quality, and flock composition. More complex equations used in their analysis were not implemented here to maintain a more simplified model that aims to capture only the key effects of flock management and value addition to agricultural production. Thus, forage quality was excluded from the current model boundary. As a result, the key assumption in the forage resources component of the model is that at this incipient stage of production the quantity of forage produced on a limited amount of land is relatively more limiting on the caprine enterprise than its quality.

(6) Forage available per caput = ZIDZ(forage resources, adult goats + weaned *cabritas*)

(7) Fractional forage needs satisfied = forage available per goat / reference forage required per goat

The forage resources component of the model consists of one stock (forage resources) with its production inflow and consumption outflow. If farmers perceive their forage resources to be insufficient, it is assumed that they will desire to increase forage production through productivity increases and land area expansion. Both land productivity and land in production are anchored on their reference values in reference multiplicative formulations. Indicated land area changes via a reference multiplicative formulation so that more land is desired when forage resources are perceived to be inadequate (Equation 8). Furthermore, producers also slightly increase fertilizer applications (Equation 9) when forage productivity is inadequate to meet flock needs. INIFAP worked with Micoxtla farmers to improve crop productivity by applying fertilizer. The inclusion of this policy in the model assumes that producers recognize the potential for increased returns with productivity gains from fertilizer applications, and that they have the capacity to purchase fertilizer or apply manure. A first order delay formulation with a three-month delay time is used in the indicated forage productivity variable (Equation 10) to calculate productivity changes from fertilizer application.

(8) Indicated land area = base amount of land in production per family * effect of perceived required forage needs met on desired area (smooth fractional forage needs satisfied)

(9) Fertilizer applied = reference fertilizer application * effect of perceived required forage needs met on fertilizer application(smooth fractional forage needs satisfied)

(10) Indicated forage productivity = SMOOTH (base forage productivity * effect of fertilizer on productivity(fertilizer applied / reference fertilizer application), fertilizer effect on forage productivity adjustment time)

Forage productivity (Equation 11) is either equal to indicated forage productivity or seasonal forage productivity (Equation 12). Seasonal land productivity changes with the pattern of rainfall though the effect of seasonal rainfall on productivity (Equation 13).

(11) Forage productivity = indicated forage productivity * (1 - seasonal rainfall switch) + seasonal productivity * seasonal rainfall switch

(12) Seasonal forage productivity = indicated forage productivity * effect of seasonal rainfall on forage productivity

(13) Effect of seasonal rainfall on productivity = (average monthly rainfall / overall average monthly rainfall) * indicated forage productivity

Average yearly rainfall patterns (Figure 2.6) from 1961 to 2003 obtained from the climatology station in Teocelo, Veracruz were used as a direct proxy for seasonal variation in forage productivity (INIFAP, 2006a). Seasonality is activated by changing the value of the seasonal rainfall switch from 0 to 1. The average individual monthly rainfall is divided by overall average monthly rainfall; and this ratio affects forage productivity in a direct multiplicative formulation (Equation 12).

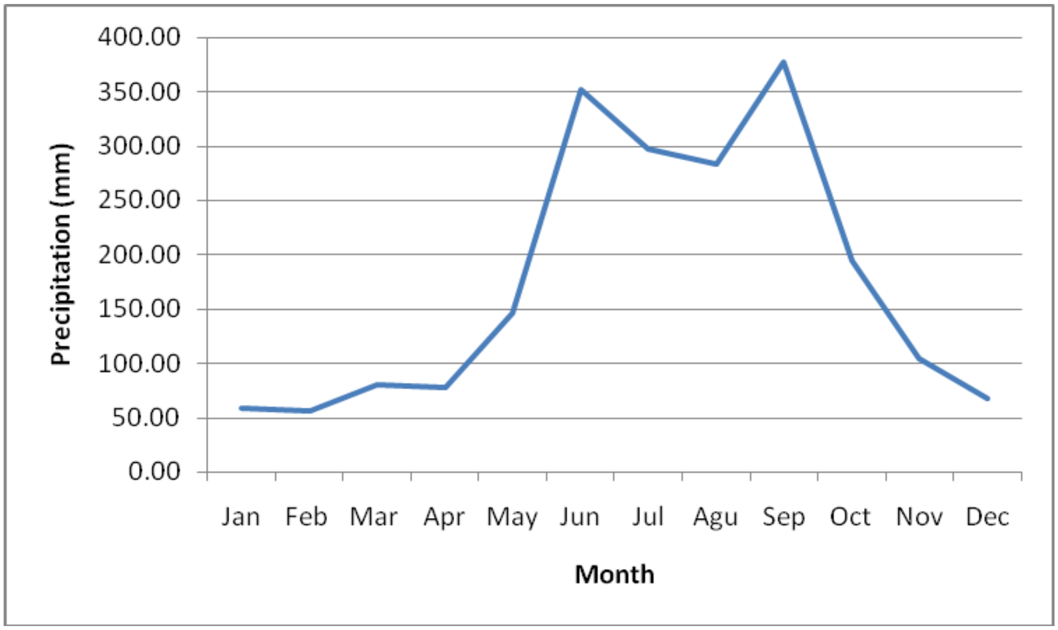

Figure 2.6 Seasonal Rainfall Patterns at the Teocelo, Veracruz Weather Station (INIFAP, 2006).

Forage production incurs several costs that affect the profitability of community caprine activities: costs of fertilizer application (Equation 14), land costs (Equation 15), and cost of labor (Equation 16). These costs collectively determine the total cost of forage production (Equation 17), and are used to define two system performance outputs[16]: the cost to produce one kg of forage (Equation 18) and returns to labor (Section 2.3.3.2.7). Forage production costs affect the monthly profitability of community caprine operations in the profitability expectations component of the model.

(14) Fertilizer costs = fertilizer applied * area in production * unit cost of fertilizer

(15) Land costs = area in production * fixed monthly cost per hectare

[16] These variables (not pictured in Figure 2.5) are important output or indicator variables in the actual model.

(16) Cost of labor to maintain and harvest forage = forage production * labor required to maintain and harvest forage * monthly rate for hired labor

(17) Forage production costs = cost of labor to maintain and harvest forage + land costs + fertilizer costs

(18) Cost to produce one kg forage = forage production costs / forage production

Forage consumption (Equation 19) depends on the number of adult goats (adult does and weaned *cabritas*) and the amount of forage consumed per goat. The quantity consumed per goat changes through a reference multiplicative formulation depending on the ratio of forage available per goat to the reference amount of forage available per adult animal.

(19) Forage consumption = (adult goats + weaned *cabritas*) * base forage consumption per goat * (effect of forage availability on consumption (ZIDZ(forage available per goat, reference forage available per goat)))

2.3.3.2.3 Milk Allocations

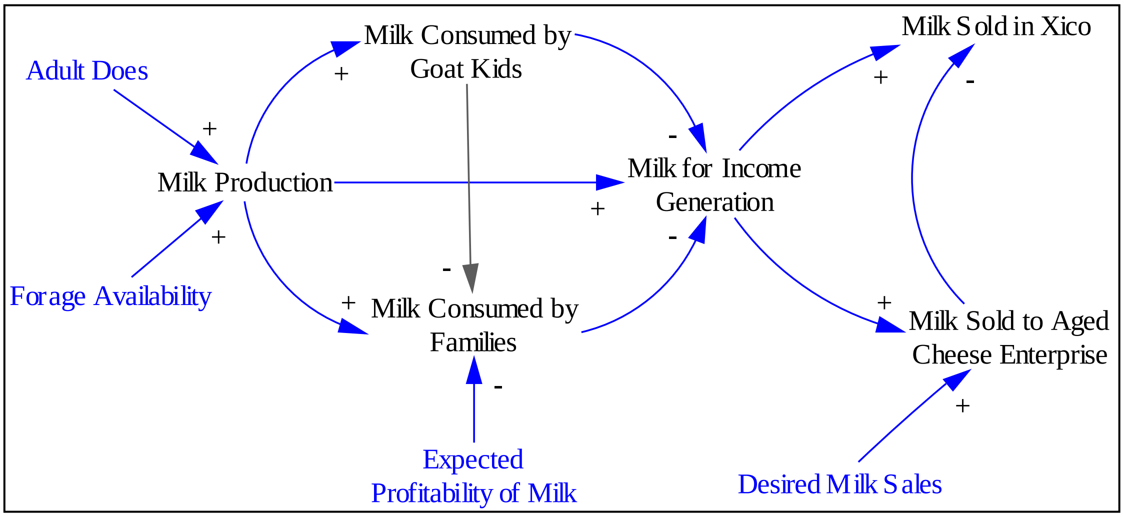

Figure 2.7 A simplified structure of milk allocations. Fluid milk is consumed by goat kids and the families raising them. Leftover milk production is allocated to income generation, and is either sold in Xico or to the aged cheese cooperative.

The milk allocations component of the model represents the use distribution of fluid milk for feeding kids, for household consumption, and for sales income. It is linked to the goat production component of the model through the stocks of adult does, c*abritos* and c*abritas*, and to the forage resources component through forage availability (forage supply). Reference multiplicative formulations were used to represent the nonlinear relationships in variables for the amount of milk consumed by the household consumption and the daily milk yield per nanny. The amount of milk for household consumption decreases when profitability from milk sales and cheese production surpasses the reference value. Milk for goat kid consumption varies as the number of young goats varies. Producers indicated that they do not restrict the amount of milk consumed by kids. Therefore, a constant daily amount was assumed (G. P. Alvarez Montes de Oca, personal communication, August 16, 2007). Milk production also varies based on forage availability, animal intake, and lactation period.

Any leftover milk after consumption by kids and the household is sold (Equation 20). The model begins with all milk available for income generation activities being sold in Xico. In order for milk to be allocated to produce aged cheese, an initial investment to establish productive capacity is required. This initial investment was assumed to occur at the simulation start time (January 2009). The assumption was made that producers will first fill the demand of the cheese cooperative before selling excess milk in Xico (Equations 21 and 22).

(20) Milk for income generation = MAX((milk production-milk consumed by kids-milk consumed by families) , 0)

(21) Milk sold to aged cheese enterprise = MIN(milk production for income generation, desired milk sales)

(22) Milk sold in Xico = milk production for income generation – milk sold to aged cheese enterprise

2.3.3.2.4 Premium Aged Cheese Production

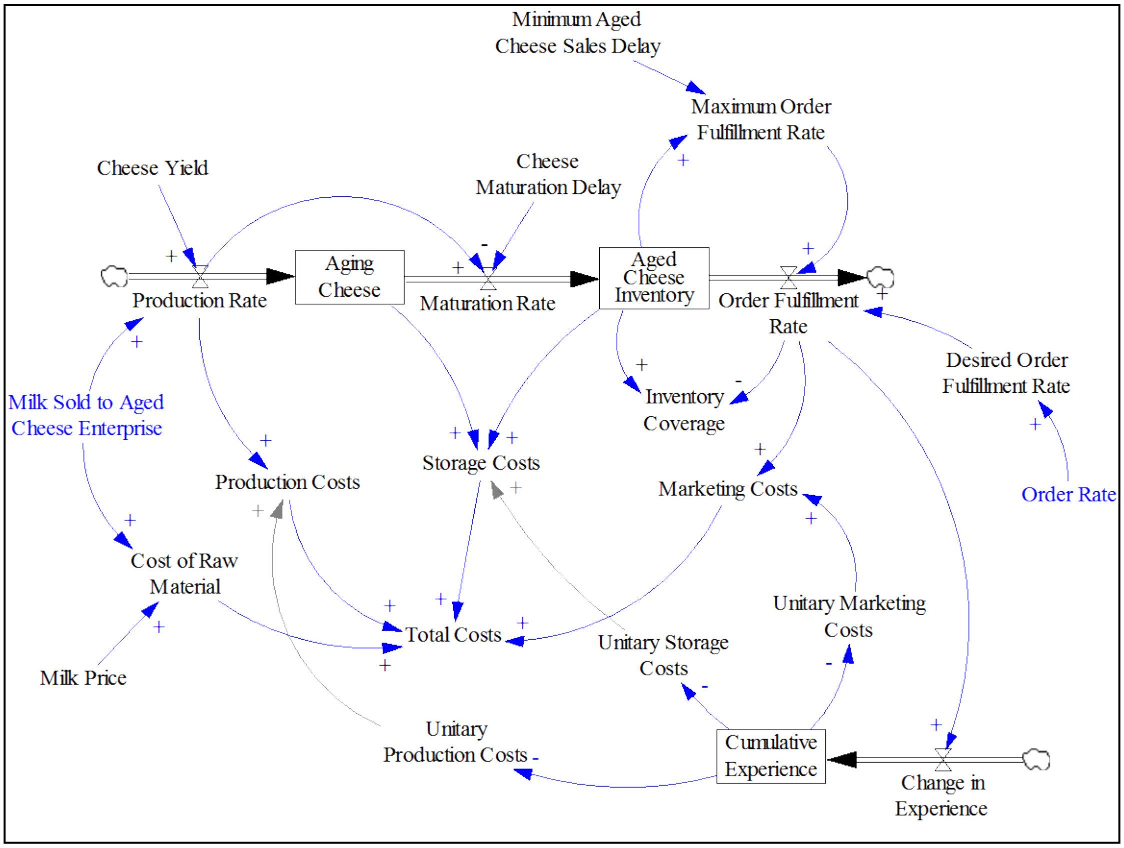

Figure 2.8 Simplified stock-flow structure of cooperative aged cheese production consisting of a two-stock aging chain.

Once production capacity is established (Section 2.3.3.2.6), purchased milk enters the aged cheese component of the model. Cheese production is determined by its yield from the processing of fluid milk (Equation 23). This production rate is an inflow to the aging cheese stock. The maturation rate (Equation 24) is the intermediate flow between the aging cheese stock and the inventory stock. It is a fixed delay of the cheese production flow. After maturation, the product is transferred to the aged cheese inventory stock. It exits this stock through the order fulfillment rate (Equation 25), which is a variation of the Fuzzy MIN function suggested by Sterman (2000). Orders are filled based on consumer demand and available inventory. Order fulfillment means cheese sales to consumers and is the sole source of income for the cooperative.

Variables depicting production costs, storage costs, and marketing costs are determined by the quantity of cheese being produced, stored, and sold, respectively. The unit cheese production costs (Equation 26) decrease over time as members of the cooperative acquire cheese making experience. Another major cost for the cooperative is the raw milk input, which the cooperative buys from producers.

(23) Production rate = cheese yield * milk sold to aged cheese cooperative

(24) Maturation rate = DELAY FIXED(production rate, cheese maturation delay, production rate)

(25) Order fulfillment rate = desired order fulfillment rate * order fulfillment table(ZIDZ(maximum order fulfillment rate, desired order fulfillment rate))

(26) Unit costs = base unit costs *(cumulative experience / initial experience) ^ strength of learning curve

The aged cheese price affects cheese revenues. The difference between revenues and costs is defined as the monthly profitability of aged cheese production. It also affects the cumulative aged cheese profitability stock and the exponentially smoothed monthly profitability of aged cheese in the profitability expectations component of the model.

2.3.3.2.5 Aged Cheese Market

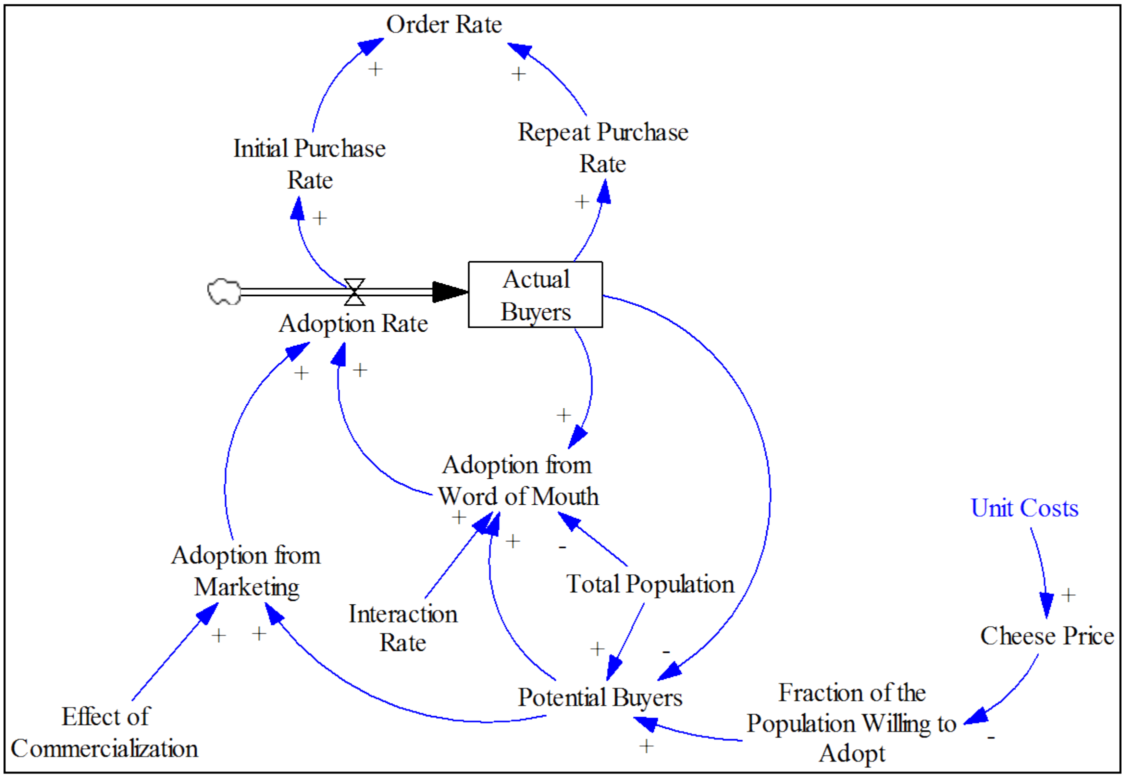

Figure 2.9 Simplified aged cheese market growth structure. The typical two-stock market growth structure (Sterman, 2000) was adapted to interface with unit costs and the price of aged cheese.

The hypothetical aged cheese market is a niche market in Xico. Clients in this hypothetical market are hotels and restaurants that serve the growing tourism industry. The aged cheese market demand structure is also the source of the expected S-shaped pattern of growth in the number of actual buyers (e.g., restaurants, hotels, and private households). This directly affects the product demand, the desired cooperative production capacity, and capacity utilization. The expected S-shaped growth is generated by this structure in the cooperative simulation (Figure 2.10). The structure was selected and adapted from the Bass Diffusion Model (Bass, 1969, as cited in Sterman, 2000), which is commonly used to estimate new product sales during the product growth phase. It normally simulates an S-shaped growth pattern in the number of product adopters, and, in this case, in the aggregate demand for premium cheese.

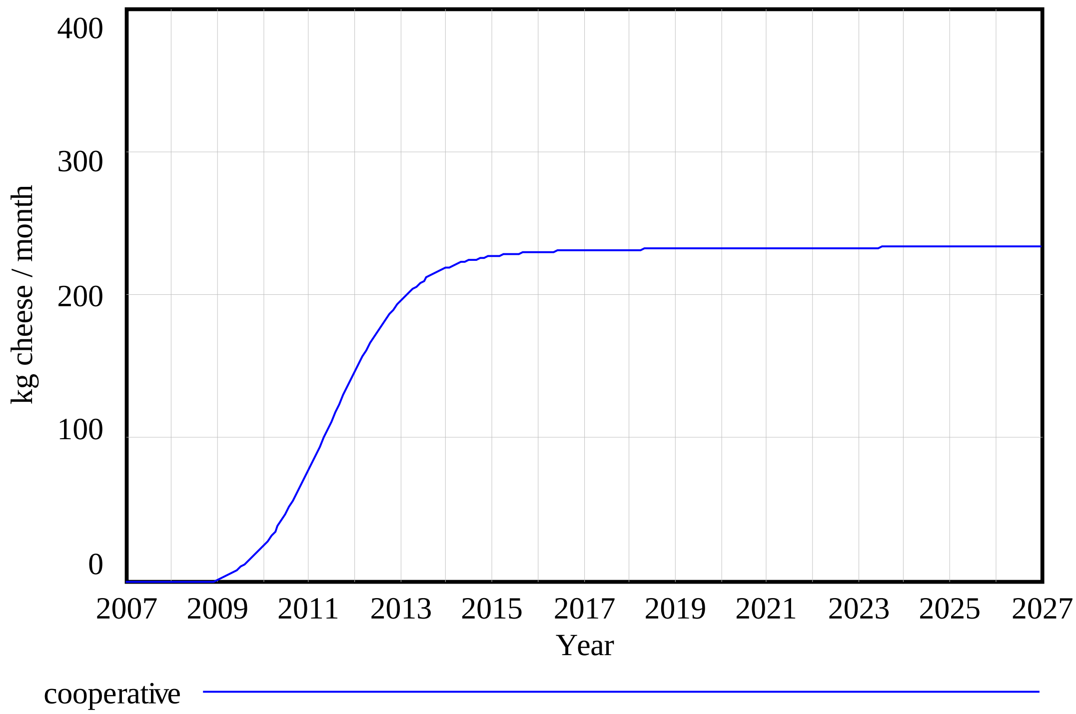

Figure 2.10 Demand for aged cheese (order rate).

The population of potential buyers (Equation 27) is determined by the population of total buyers, the current number of actual buyers, and the fraction of the population willing to adopt the product. The number of potential buyers is constrained by the fraction of the total population willing to adopt, which prevents the entire population from becoming potential buyers unless the price of aged cheese is extremely low. The adoption rate (Equation 28) is the only inflow into the actual buyers stock. It is the sum of adoption from interaction and adoption from word of mouth. Adoption from word of mouth (Equation 29) depends on the interaction between actual buyers and potential buyers. It is constrained by the buyer interaction rate. The total population variable includes test structure to evaluate the effect of changes in market size on model behavior.

With the exception of unit costs and cheese price, the structure functions exogenously to the rest of the model to determine market demand. The limiting factors for market growth are the total population of potential buyers, the effectiveness of commercialization, and the buyer interaction rate.

(27) Potential buyers = MAX(Fraction of the population willing to adopt * total buyer population – actual buyers, 0)

(28) Adoption rate = adoption from interaction + adoption from marketing

(29) Adoption from word of mouth = ZIDZ((buyer interaction rate*proportion of adopters*actual buyers*potential buyers),total population)

2.3.3.2.6 Cooperative Aged Cheese Productive Capacity

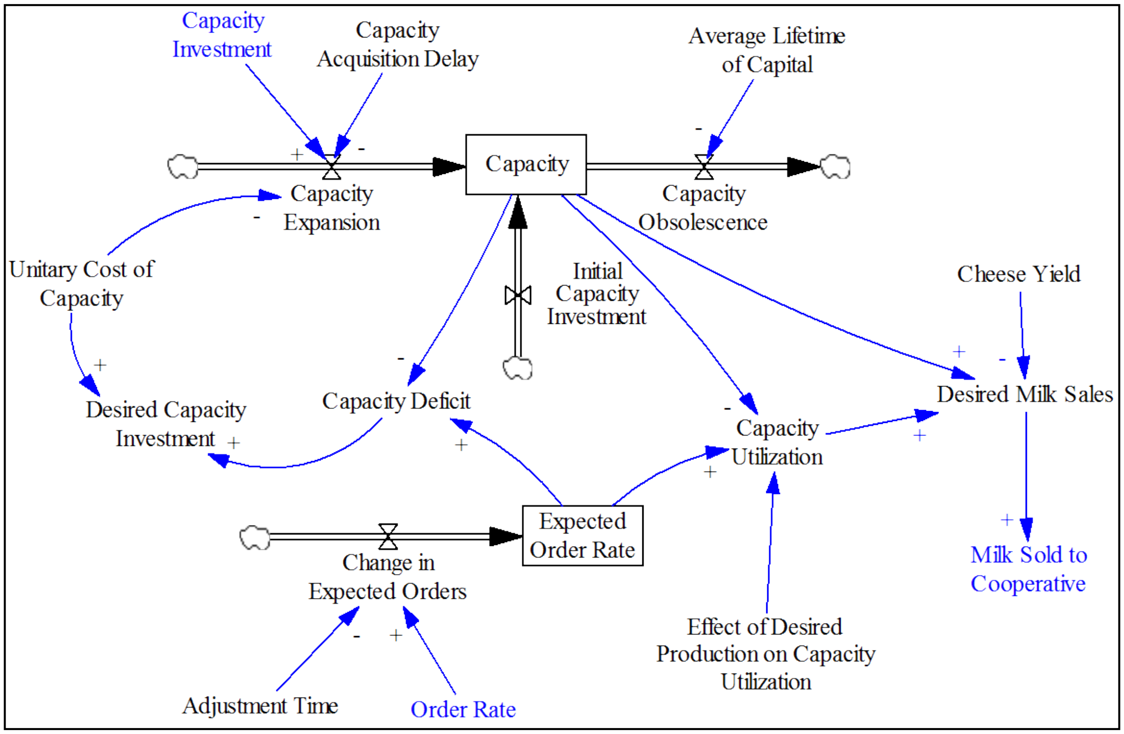

Figure 2.11 Productive capacity and utilization structure for the cheese cooperative. Productive capacity is a single-stock structure. Capacity utilization structure is also included.

The general productive capacity structure was adapted from Henderson's (2007) early growth stage cooperative modeling work. The aged cheese cooperative initializes its operations by making a small initial investment in production capacity at the same time that marketing commences, which is year two of the simulation (January 2009) given default assumptions. Following an exogenous initial investment, the capacity expansion structure acquires capacity endogenously. The capacity expansion inflow (Equation 30) to the capacity stock permits expansion when there is a desired capacity investment (Equation 31) and financial conditions in the cheese cooperative allow for capacity investment. The description of capacity investment decisions is located in Section 2.3.3.2.7. Desired capacity investment responds to expected demand via the capacity deficit variable (Equation 32). Capacity also depreciates over time through a first order delay in the outflow from the capacity stock.

(30) Capacity expansion = DELAY FIXED(capacity investment / unitary cost of capacity, capacity acquisition delay, 0)

(31) Desired capacity investment = capacity deficit * unitary cost of capacity

(32) Capacity deficit = MAX(0, expected order rate - capacity)

Capacity utilization (Equation 33) is a function of the ratio of expected orders[17] to capacity in a reference multiplicative formulation. Capacity utilization is then used to compute desired milk sales (Equation 34), which directly affects the quantity of milk sold to the cooperative in the milk allocation structure.

(33) Capacity utilization = effect of desired production on capacity utilization (ZIDZ(expected order rate, capacity))

(34) Desired milk sales = (capacity/cheese yield) * capacity utilization

[17] The expected orders (demand) variable is equivalent to desired cheese production.

2.3.3.2.7 Cheese Cooperative Decisions and Accounting

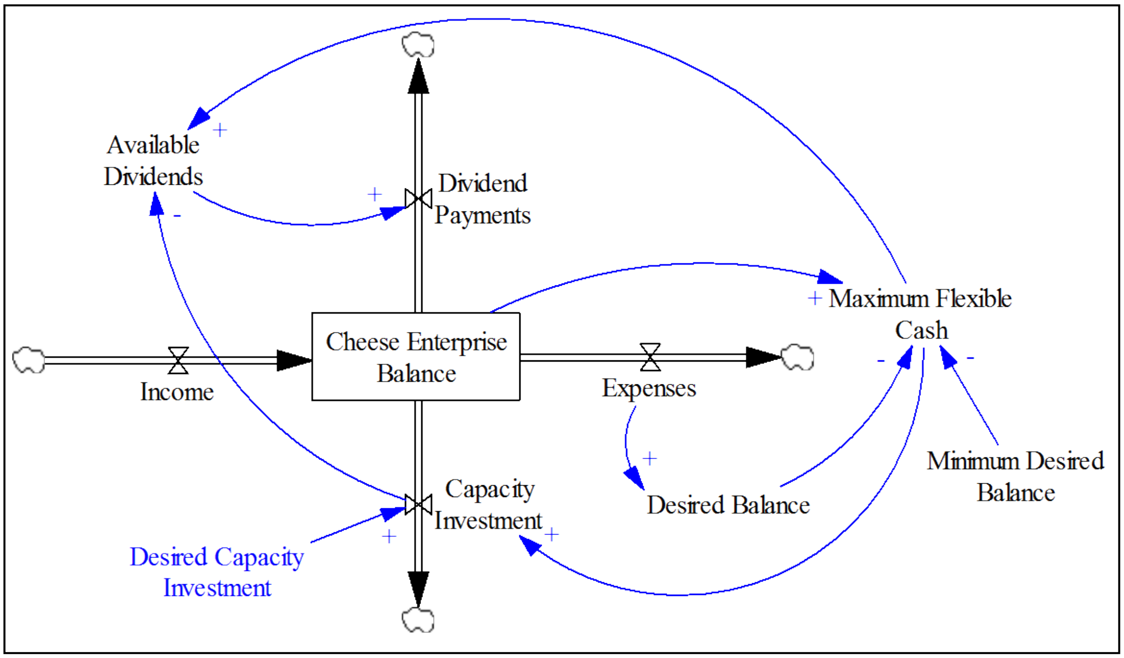

Figure 2.12 Simplified structure of cheese cooperative decisions and cash holdings. This single stock structure computes the difference between income and expenses over time given the cooperative management policies.

The aged cheese enterprise is conceptualized as a small cooperative. It is assumed that the objective of the cooperative is to maximize economic returns to farmers who sell raw milk to the cooperative. Therefore, after capacity investments are made, surplus is paid to participating farmers as dividends. Alternatively, farmers can be paid a higher price for raw milk or compensated through a combination of dividends and higher milk prices. These scenarios are evaluated in the policy analysis section (Chapter 3.2).

The core element of the cheese cooperative decision-making structure is the cheese enterprise balance stock (cash holdings). The income inflow and expenses outflow from the stock are exogenous to the decision-making structure, and are instead calculated directly based on the actual amount of cheese in production. The capacity investment and dividend payments outflows are critical to the performance of the cooperative. The maximum flexible cash variable (Equation 35) is used to determine when capacity investments and dividend payments can be made. It selects the minimum value between the difference between the cheese enterprise balance and the minimum desired balance, and the cheese enterprise balance and the desired balance. It also prevents negative values by using the MAX function. The desired balance (Equation 36) is determined by costs and cost coverage time. This maximum flexible cash management formulation was chosen to help prevent negative values in the cheese enterprise balance stock when seasonal production is activated. It assumes that an objective of the cooperative's management is to maintain sufficient cash on hand to cover expected expenses for future months to prevent times of economic crisis due to seasonal market uncertainties.

Therefore, the cooperative will invest in capacity (Equation 37) when there is a desired investment in capacity (Equation 31) from the cheese cooperative productive capacity structure (Figure 2.11) and sufficient flexible cash on hand to make the investment. It is assumed that the cooperative will always fulfill desired capacity investments before paying dividends to farmers. This is important primarily in the initial stages of the simulation as the cooperative expands capacity to meet consumer demand. This assumption may not be reasonable later in the simulation, but unless further market expansion occurs, the effect on model behavior is minimal. If excess flexible cash is available after fulfilling desired capacity investments, dividend payments can be made (Equations 38 and 39). Rather than pay quarterly, six-month, or annual dividends, this hypothetical cooperative pays dividends on a continual basis after becoming solvent. For the purpose of this analysis, cooperative solvency is defined as the time when the cooperative is able to fulfill desired capacity investments and begin making dividend payments given the cooperative management structure.

(35) Maximum flexible cash = MAX(0, MIN(cheese enterprise balance – minimum desired balance, cheese enterprise balance – desired balance))

(36) Desired balance = costs * cost coverage time

(37) Capacity investment = MIN(desired capacity investment / cheese enterprise balance adjustment time, MAX(0, maximum flexible cash / expense time))

(38) Available dividends = MAX(0, (maximum flexible cash – expense time * capacity investment)/dividend expense time)

(39) Dividend payments = available dividends * dividend activation switch

2.3.3.2.8 Profitability Expectations

The monthly profitability variables compute the monthly profitability of the different enterprises involved in the aggregate community caprine operations (Section 2.3.3.1). These include: goat production (*cabrito* and culled goat sales), milk production, and dividend receipts. They are used as the inputs in their respective smooth monthly net margin (Equation 40) variables. These variables represent goat producers' expectations about the profitability of goat production and milk production. Each variable is given a distinct adjustment time depending on the estimated information delay in adapting expectations about profitability. These variables were designed using an adaptive expectations formulation with third order exponential smoothing. They are used to determine producer decisions about the reinvestment of profits in different goat enterprises (e.g., goat purchases) and the culling rate. In addition, the expected profitability of fluid milk sales affects household milk consumption in a reference multiplicative formulation. Other forms of reinvestment are ignored in this model.

(40) Expected profitability = SMOOTH3(monthly profitability, smooth adjustment time)

Cumulative profitability variables and final time cumulative profits variables are also included in this component of the model for optimization and cumulative profitability tracking purposes of the distinct enterprises in the goat operation.

Seasonal milk price trends are also contained in the profitability expectations model component. These prices can fluctuate up to 50% between the dry season and rainy season based on the quality, supply, and demand for milk (Holmann, 2001). This trend is exogenously imposed so that milk prices oscillate between $4.5 pesos/kg during the dry season and $3.5 pesos/kg during the rainy season.

Finally, other important indicators and goat enterprise performance include returns to labor (Equation 41) and income over feed costs (Equation 42). Although these variables were ignored in the endogenous structure, they are likely important to producer decision making. Family labor contributions were assumed to be gratis. Forage production costs affect the monthly profitability of community caprine operations in the profitability expectations sector of the model

(41) Returns to labor = (monthly profitability of community caprine activities / number of families) / monthly hours worked per family

(42) Income over feed costs = milk sales income + culled goat sales income + *cabrito* sales income + dividend income – forage production costs

2.3.3.2.9 Interactive User Interface

The user interface was designed so that the INIFAP team could experiment with different test inputs and examine their effects on model behavior. It was used by the INIFAP team for model evaluation and policy analysis exercises during the introductory course.

CHAPTER 3

RESULTS AND DISCUSSION

This chapter comprises two sections. First discussed will be the learning process undergone by the INIFAP team during the system dynamics course. The second section describes a policy analysis that evaluates the basic economic feasibility of the cooperative under various conditions. Alternative cheese cooperative management scenarios and responses to external production and market disturbances will be discussed based on simulated results using the value-added cooperative model. Finally, comprehensive parameter sensitivity testing will be assessed.

3.1 Introductory System Dynamics Course Summary

The short course contained 66 h of instruction. Sixteen individuals attended at least one session. However, only eight (six men and two women) of these sixteen were consistent participants throughout the course. The average in-class participation by these individuals was 53 h with a maximum individual participation of 66 h, and minimum participation of 32 h.

The course was theory-based due to time constraints by INIFAP team members. Twenty-one two-to-three-hour presentations covered the primary course materials. The lectures provided an intensive introduction to systems conceptualizations and dynamic modeling using the system dynamics problem assessment method (Section 2.1.6). Numerous practical exercises were also completed in-class. Homework exercises were assigned but with a low completion rate by most participants. To compensate for time limitations, practical learning was achieved through group and small team model building exercises during and outside course sessions. In addition, a final two-day workshop was dedicated to the review of all information and concepts presented during the course. This activity also introduced new topics such as the use of data in models and an exercise about initializing models in dynamic equilibrium. All INIFAP-Xalapa faculty that participated in any part of the course attended the closure and at least one additional session during the final workshop.

A key pedagogical component of the course was devoted to team model building exercises (Section 3.1.3). During the course, the best discussion occurred in the well-attended team model building presentations. Participants also learned from and evaluated a preliminary model on value-addition to milk. Comments and recommendations by INIFAP scientists for the model are summarized in Section 3.1.4.

3.1.1 System Dynamics Course Evaluation

This section is devoted to evaluating the outcomes of the system dynamics course and factors that led to both favorable results and desired learning challenges for the INIFAP team. Although interest and awareness about the benefits from systems conceptualizations and modeling techniques were high, few participants have continued to work with the method. Course evaluations provided insight into the reasons behind its limited continuation.

Course evaluations consisted of a brief informal survey that was designed and implemented by a social scientist on the INIFAP team. The results were processed by INIFAP and provided to the course instructor to improve future system dynamics training. Informal feedback was also obtained during the course and contributed to the forthcoming discussions.

3.1.1.1 Time Constraints

The primary limitation to learning for course participants was the lack of time to complete practical exercises. In addition, there were scarce institutional incentives to participate in the course. It took place during normal working hours, which competed with daily job responsibilities. Therefore, depending on the individual motivation to learn system dynamics principles, there was a varying degree of subject matter comprehension.

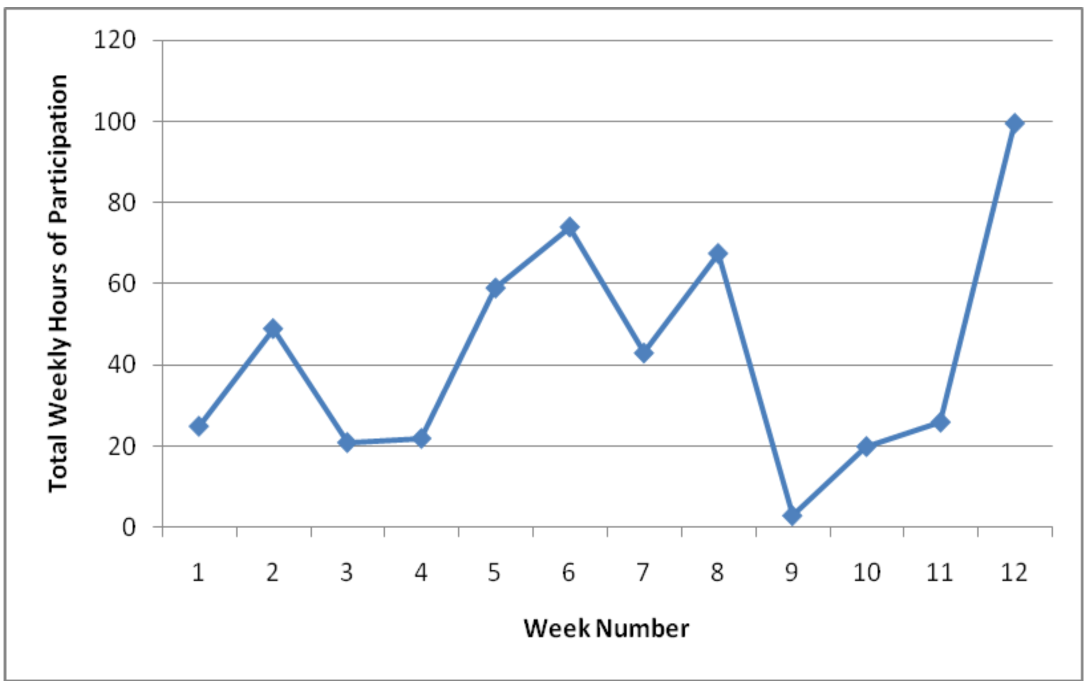

Figure 3.1 Total hours of weekly course participation by all participants.

Figure 3.1 illustrates the total hours of weekly class participation by all enrollees during the course. Excluding the final workshop in week twelve, the largest number of participants attended the sessions in week two, hence the initial peak in total participation. After week two, participation was normally limited to eight participants. Participation during weeks three and four was low because of the International Micro-watershed Workshop, which demanded the attention of all INIFAP personnel. Following the workshop, most course materials were delivered during three weekly lectures between weeks five and eight. During week nine, only one enrollee attended the single lecture. Finally, the peak in participation during week 12 occurred due to the intensive two-day workshop that concluded course activities. Seven individuals attended the entire workshop while a total of thirteen attended at least one session in addition to the course conclusions. This overwhelming response in participation during the final workshop provided evidence for the perceived value of the system dynamics short course for the INIFAP team.

When constrained by time, it would be prudent to focus on problem conceptualization and less on simulation modeling. The INIFAP leaders originally recommended holding course sessions from 10:00 am to noon. However, participant evaluations revealed that a course held during office hours should instead be conducted in the afternoon when more time is available to complete practical assignments due to a typically lighter workload.

3.1.1.2 Interpretation of System Dynamics Principles

One principal challenge with the interpretation of system dynamics conventions and terminology in Spanish surfaced during the course. This was the definition of delays. The INIFAP team interpreted a delay as something that occurred later than intended. For example, a plane that arrives later than the scheduled arrival time fits this notion of a delay. However, a delay process in system dynamics is any flow of material or information in which the outflow from a stock lags in time its inflow (i.e., a time delay). Therefore, delays occur through stocks, which separate a stock's inflows from its outflows (Sterman, 2000). This permits the accumulation of material or information in stocks.

Common delays include average delivery delays, perception time delays, and average maturation delays. This misinterpretation of delay processes was clarified once it was identified.

3.1.1.3 Behavior over Time

During the initial part of the course, participants learned about the addition of the dynamic time element to problem analysis, and the variety and characteristics of dynamic behavioral response patterns over time for biophysical and social problems. Course participants were challenged in conceptualizing dynamic problem evolution. Habitually, problem analysis was considered only as static images of the problematic situation before and after project interventions. Given a problem and asked to draw it's evolution in time, the tendency was to draw a straight line or a combination of straight lines. Therefore, a lecture and supporting exercises were devoted to depicting reference mode behaviors for different problems. After several iterations, and an introduction to the fundamental modes of dynamic behavior[18], straight line expressions became curvilinear ones, and the reference behavioral modes drawn by course participants began to resemble fundamental behavioral responses.

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[18] Exponential growth, S-shaped growth, goal seeking, oscillation, and overshoot and collapse are fundamental modes of behavior in complex systems (Sterman, 2000). The ability to identify and analyze these behaviors in graphs of behavior over time was a key element in early lectures.

3.1.1.4 Vensim PLE® Software

The software used to develop basic dynamic simulation models was Vensim® PLE, the functional learning version of software by Ventana Systems, Inc. The user interface was difficult for the course participants to use. Comments were made that the software was unattractive possibly due to a lack of understanding of the software's purpose and capacity. In addition to this initial experience using it, Vensim® is quite different from typical software tools used by the INIFAP team. Probably with further experience using the software, and greater understanding of dynamic modeling techniques, Vensim® would become a more attractive tool. Also, Vensim® may be easier to learn and more user-friendly than other software frequently used by INIFAP (e.g., ArcGIS).

3.1.1.5 Model Formulation

Related to the use of Vensim®, course participants expressed frustration in the transition from a conceptual model to a simulation model. This outcome was anticipated because model formulation is one of the most challenging steps in the modeling process. Participants struggled to formulate the necessary equations to properly quantify their simulation models. Many common system dynamics formulations are abstract compared to the quantitative formulations typically used by the INIFAP team. One participant used the Fuzzy MIN[19] function as an example by saying, "Although the

[19] The FUZZY MIN function uses a reference multiplicative formulation to determine the manner in which a variable or rate is affected by more than one limiting factor. Rather than using a simple MIN formulation, FUZZY MIN permits a more gradual adjustment between the two constraining factors. For example, it could be used to approximate cheese sales when either inventory or orders may be limiting.

function appeared to be useful, I never fully grasped the mathematical justification for the function and was unable to successfully incorporate it into a simple model." Additional time, practice, and experience working with existing models are necessary to accurately define the equations and decision rules used in system dynamics applications.

The INIFAP team also identified the need to strengthen quantitative skills, which may be associated with the team's reliance on software results from processed data. For example, one of the most challenging learning exercises was graphical integration and differentiation, a simple and useful method to intuit the behavior of stocks from a graphed representation of their flows, and vice versa. By the end of the course, participants could better interpret graphical representations, and could identify the patterns of dynamic behavior and predict the likely feedback loop dominance associated with each behavioral response. Consequently, participants gained understanding about the relationship between structure and behavior. Several participants acknowledged greater ability to interpret response functions presented in scholarly articles.

3.1.1.6 Spatial Limitations

Much of the work undertaken by INIFAP - LADIGS focuses on spatial interactions using geographic information systems (GIS) modeling. Therefore, for the LADIGS team an important limitation of the system dynamics modeling process is that the method is typically non-spatial or that it aggregates elements of the spatial component. For example, the value-added cooperative model aggregates the spatial component into the average land area in forage production per family. Thus, the method focuses on dynamic processes involved in problem analysis, and provides a conceptual and policy analysis tool to help understand and interpret the changes in pixel level data over time (Nicholson, personal communication, July 5, 2007). It is not normally used for explicit representation of detailed spatial processes.

Integrating GIS information into system dynamics models is a major task. One option is an intensive method in which each pixel is modeled as a stock and represents a geo-referenced household, plot of land or location in a watershed. Decision rules determine the flow of runoff, nutrients, or information among the stocks. Another option is the linkage of spatially explicit data to dynamic simulation models. The PC-Raster DOS-based software has been designed for the purpose of combining dynamic and spatial data.

The INIFAP team is interested in exploring linkages between GIS models and system dynamics models that represent spatial changes over time driven by important feedback processes. However, traditional system dynamics methods do not incorporate detailed spatial elements. This is a future goal for the INIFAP team.

3.1.1.7 Contrasting Methods

The portfolio of problem analysis and conceptualization techniques used in INIFAP's sustainable micro-watershed program mainly consists of qualitative participatory techniques. One short-course participant metaphorically summarized their methods akin to a doctor's visit consisting of diagnosis, analysis, and a correlated treatment. Sterman (2000) defines this technique as an event-oriented world view rather than a feedback-oriented one.

Specifically, the INIFAP approach to participatory watershed development begins with the selection of priority watersheds based on perceived environmental and socioeconomic problems in targeted regions (INIFAP, 2006b). The second step is to conduct, and subsequently evaluate, a baseline study comprising seven linked activities[20]. A baseline study may require several months to complete. Based on the information obtained, the team constructs a problem matrix and a matrix of objectives to analyze and sift the emerging priority solutions (INIFAP, 2006b). Finally, a participatory action plan is designed and implemented.

Team members said that they make decisions primarily using classical trial and error methods. After the short course they now ask how errors can be avoided, posing more questions to challenge preconceptions. For example, "Would the community have benefitted more by simply investing capital to improve infrastructure than what was achieved in all other micro-projects?" Many rustic infrastructure inputs and production inputs were provided by the INIFAP mountain project to encourage participation in household gardens and greenhouse production enterprises. This resulted in a community expectation for external inputs[21]. Now that the micro-watershed community development project is in its final stages, INIFAP is evaluating ways to make these projects more self-sustaining by reinvesting agricultural profits to sustain projects in the long-term. For example, profits from sales of greenhouse tomatoes, initially

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[20] The seven linked activities include: 1) Overall problem conceptualization, 2) participatory baseline workshop, 3) selection of indicators for evaluation, 4) development of community survey, 5) random sample selection, 6) application of community survey, and 7) participatory rural workshop to triangulate the acquired information.

[21] Examples of external inputs include: fertilizer, seeds, greenhouse materials, chicken coup materials, improved stove materials and corral construction materials.

funded by INIFAP, are being set aside for greenhouse repair and maintenance.

Endeavors may become self-sustaining sooner by avoiding the initial effects of this established dependency. An *ex ante* analysis of the core community problems and interventions may help prevent community dependency on outside inputs.

The short course also revealed that important feedback processes affecting problematic behavior are ignored. Instead, decisions primarily based on mental models[22] are predicated on an event-oriented framework comprising causes, problem effects, objectives, and solutions. As a result, many participants encounter difficulties conceptualizing feedback processes among key variables and the proposed solutions. For example, one participant presented the problem of water contamination in households located near water sources. A proposed solution was to build dry compost latrines to prevent contamination. However, other factors were not considered, such as cultural limitations, animal contamination, and long-term use and maintenance problems that could result in leakage. By the end of the course, this participant began to evaluate the short and long-term implications of proposed solutions, and was better able to also consider the dynamic complexity of the problem.

3.1.1.8 Changes in Problem Conceptualization

Considerable learning occurred about the conceptualization of dynamic problems during team model building exercises, which allowed participants to objectively complete phases of the modeling process. Each team developed a

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[22] In this case, mental models are the experience-based intuition of INIFAP personnel and participating farmers.

working causal loop diagram that defined feedback processes. One participant identified the need to relate models to reality to produce more realistic depictions of real world processes. Course participants learned the importance of attaining an advanced understanding about problem complexity to develop realistic and useful simulation models.

Course participants were asked how their thinking was influenced by the course. A member of the child malnutrition team (Section 3.1.3) noted, "System dynamics made me think more and ask, 'What would happen if…?'" These "What if…?" questions are particularly useful in social science research where policy analyses often lead to more questions and intensive speculation about socioeconomic problems (Bardach, 2004). For example, several participants asked, "What would happen to vegetable commercialization projects if we had not provided fertilizer inputs gratis? How would it affect the long-term sustainability of the project and farmers' perception of ownership in the project?" This type of question is often appropriate for analysis assisted by system dynamics methods, i.e., simulation of socioeconomic development problems and proposed interventions where few other alternatives can provide insights into these complex problems.

Group model building interventions provide an opportunity to test these different "What if" scenarios during the model building process. Furthermore, group model building also empowers modelers and stakeholders to take ownership in the analysis to help assure congruent policy goals, objectives, problem understanding, and interpretation of simulated policy results (Zagonel et al., 2004). The utility of seeking answers to "What if" questions is grounded by dynamic simulation, which permits rapid *ex ante* assessment of multiple policy alternatives.

During small team model building exercises (Section 3.1.3), several participants were also able to recognize the importance of defining the model boundary to distinguish the problem from the system. This was also identified as a limitation of system dynamics methods because some participants felt that valuable model structure and details were frequently placed outside the model boundary. The importance of problem articulation, and specifically the purpose of a model, was acknowledged as a vital factor to defining the model boundary. Overall, the problem analysis procedure used by course participants is beginning to contemplate important feedback processes that could be present in complex problems.

INIFAP has done a commendable job of forming participatory development relationships with rural households, which is palpable by the high level of participation and technology acceptance among micro-watershed development project participants. Systems thinking aided by dynamic modeling could provide decision support for project implementation by helping to better identify limiting factors, sources of policy resistance, unintended consequences[23], and high-impact entry points for future community micro-watershed initiatives.

Course participants also explained what they would change in their past micro-watershed development work if they had received system dynamics training prior to the start of the project. Regarding goat production, several participants said that infrastructure such as corrals and raised sheds was not a

[23] Unintended consequences occur when the results of a policy intervention differ from the expectation. For example, a positive unintended consequence of value-added vegetable sales to improve household incomes is improved food security for rural families that consume the vegetables. Conversely, unintended consequences often comprise undesirable secondary results.

priority in the original baseline study, but became the highest ranking factor in the final evaluation. The team believed that completion of an *ex ante* assessment prior to project implementation would have altered their initial strategies. Management and infrastructure would have been given higher priority before initiating health and sanitation programs. An important feedback process had been omitted by focusing on health and sanitation solutions without first improving the facilities and dietary management of the flock.

Another team member reflected on the social complexity of community development work, identifying it as a limitation to the team's progress in rural communities. The participant would have placed more emphasis on understanding social and cultural community dynamics as a prerequisite to initiating community development projects. In addition, more time would have been invested to organize and motivate groups prior to project initiation. As a result, collective action could have been better capitalized for the benefit of the entire community. An example of a successful method for collective action is the *Grupo Ganadero de Validación y Transferencia de Tecnología* (GGAVATT). Developed by INIFAP, this farmer organization model is well known and widely implemented in Mexico, and provides an organizational framework for research and innovation by agricultural producers with common objectives (Aguilar et al., 2005).

In the community micro-watershed development project, INIFAP facilitated the establishment of small-scale commercial vegetable production enterprises. Most time was invested to increase production without assuring the presence of a market. After conducting policy analysis and model evaluation exercises with the value-added cooperative model, participants realized the importance of understanding market dynamics. They began to consider important feedback loops associated with the market, and made plans to conduct a market study for high-value vegetables in the Xico region. All members of the mountain micro-watershed development team said they would have begun working sooner with community members to evaluate commercialization potentials of agricultural products rather than focusing exclusively on food security and nutrition during the initial stages of the program.

The team expressed that it is not always effective to look for the immediate solution due to the dynamic complexity of community development. In the future, this team will think more critically about the problems they encounter by considering the feedback processes, constraints to success, and the evolution of problems over time. System dynamics training led to more critical thinking by the team and, expectantly, will facilitate better *ex ante* assessment and overall decision making in the future.

3.1.2 Potential Contributions of System Dynamics Methods to Existing INIFAP Programs

Table 3.1 summarizes several important components of existing programs at the INIFAP Campo Experimental in Xalapa. It substantiates the potential contributions and compatibility of system dynamics modeling and existing INIFAP initiatives.

Table 3.1: Potential system dynamics contributions to INIFAP Programs

INIFAP Initiative	System Dynamics Contribution
Micro-Watershed Development Programs	• An *ex ante* impact assessment aided by system dynamics modeling could improve the sustainability of project outcomes.

	• An *ex ante* analysis should be used to assess problems identified (e.g., seasonal shortages in maize for household consumption) during the diagnostic phases of the baseline study and to evaluate proposed solutions.
Spatial Analysis	• System dynamics is valuable to assess, understand, and interpret the changes in pixel level data over time without focusing on the detailed complexity of pixel level changes. • INIFAP could become a leader in developing linkages between system dynamics models and GIS models.
Crop Productivity Potential	• INIFAP evaluates crop production potential for a variety of agricultural crops throughout Mexico, normally completed using GIS modeling based on comprehensive climatic data. • Use system dynamics modeling to assess changes in production potential over time based on historic and predicted climate-change trends, soil nutrient dynamics, and other factors.
Agricultural Research	• System dynamics could aid the evaluation of research results to develop policy recommendations for farmers. • For example, to assess the impacts of strategies to diversify the coffee plantation based on INIFAP research.
Agricultural Technology Development	• Conduct *ex ante* impact assessments of proposed technologies to determine their possible impact on rural livelihoods over time.
Participatory Decision Support for Community Development	• INIFAP has used participatory information gathering methods to drive linear ranking software for decision support using development problem prioritization matrices. • System dynamics emphasizes feedback, changes over time, and non-linear relationships. When applied as a combinatorial set of *ex ante* impact assessments, improvements may be expected in decision support, understanding, and ranking while helping prevent policy resistance and unintended consequences.

3.1.3 Team Model Building Case Studies

The problems selected by small teams of two to three course participants with common research interests included: diversification of the coffee plantation to increase economic returns to land and labor, child malnutrition in highland communities, and obesity in Mexico. These cases, although still in the early stages of development, provide evidence of participant responses about useful applications of systems thinking and dynamic modeling as an *ex ante* impact assessment mechanism in agricultural and rural development.

All three teams successfully completed phase I of the modeling process by describing the selected problems both verbally and with actual or hypothetical behavioral reference modes. The coffee diversification team designed the reference mode graph in Figure 3.2 to explain past behavior and hypothetical future behavior over time.

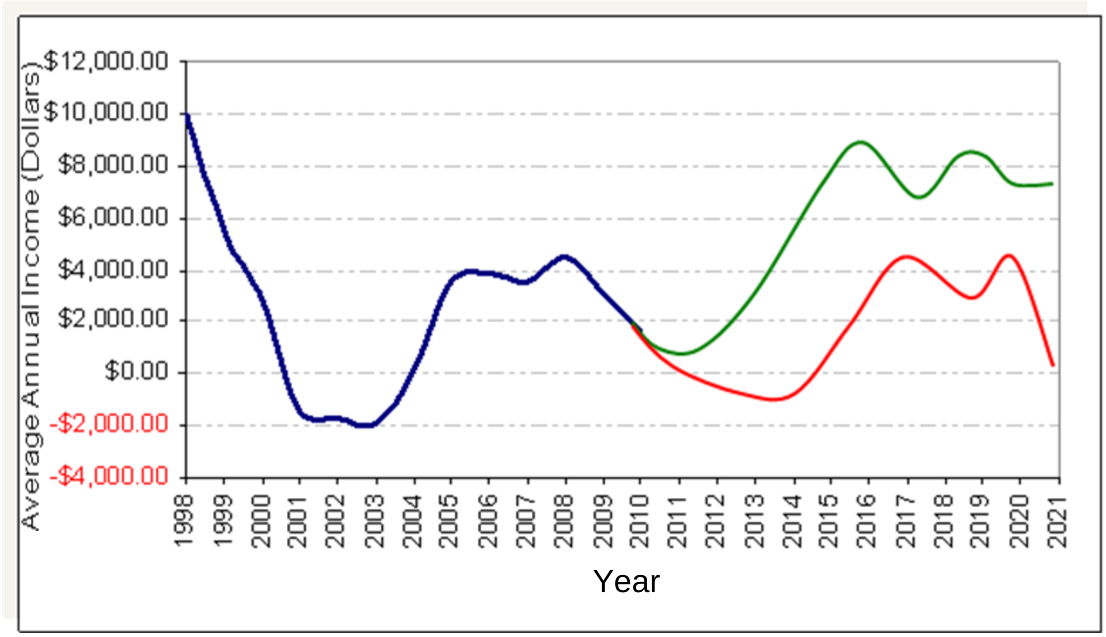

Figure 3.2 Behavioral reference mode for the diversified coffee plantation team. Average annual income from coffee is plotted versus time. The blue line indicates historic behavior. The green (upper) line shows the desired pattern of future behavior with diversification. The red (lower) line is the pattern of future behavior without diversification.

Phase II of the modeling process, the elaboration of a dynamic hypothesis, was challenging to all teams. They initially found it difficult to relate feedback structure to the behavioral reference mode. After multiple attempts and revisions to the principal feedback processes, all teams successfully developed conceptual causal loop diagrams as dynamic hypotheses for explaining the problem behavior over time. This was a notable achievement. It indicated adaptations in thinking about important feedback processes in the system. Furthermore, all teams acknowledged the importance of earning high level understanding about the problem. Teams were forced to critically evaluate their mental models of the problem through further research and evaluation of existing data, publications, and other information to more accurately relate structure to behavior. By the end of the course each team better understood the dynamic complexity of their chosen problem.

3.1.3.1 Diversified Coffee Plantation

The diversified coffee plantation team made considerable progress during the system dynamics course. This study was continued as part of an economics thesis at the University of Veracruz campus in Xalapa. This diversification scenario is important to INIFAP because it has been the focus of extensive research and investment by the Campo Experimental in Teocelo. The primary investigator identified the problem as “very challenging and dynamically complex,” and expressed frustration about understanding the complexities of the data using statistical methods. Recommendations for coffee farmers were extremely difficult to provide based on experimental results. Therefore, INIFAP was interested in system dynamics methodology to help understand the implications of the data and to conduct simulations of proposed policies for coffee producers in the region. Multiple iterations of the problem articulation, dynamic hypothesis, simulation model, and model testing steps in the system dynamics modeling process were completed. The University of Veracruz student ultimately published a thesis entitled, *Diversificación productiva de cafetales: Un análisis de riesgo y rentabilidad mediante la aplicación de Dinámica de Sistemas* (López Ramírez, 2008).

López Ramírez (2008) evaluated the economic implications of coffee diversification with chamaedorea palm (an ornamental plant), plantains, and lumber production. It used system dynamics methods and econometrics methods. The purpose of his model was to evaluate these options over time to determine long-term, economically viable options for farmers. This model could become a valuable tool to complement INIFAP's existing research. It could also be used to identify limiting factors critical to the success of future coffee diversification initiatives. The perceived utility of this system dynamics modeling effort by the INIFAP team is vital to determine whether the method will be accepted and integrated into future plans as a complementary *ex ante* impact assessment tool.

3.1.4 INIFAP Feedback on Value-Added Cooperative Model

During the introductory systems thinking and dynamic modeling course, INIFAP participants completed various group model building activities associated with the value-added cooperative model. Course sessions (Appendix I) included examples of each phase of the modeling process. Following each, a practical exercise was assigned to evaluate the preliminary results and make suggestions to improve the model. As part of model evaluation, teams also completed the process for model components that were assigned to them. INIFAP participants contributed expert subject matter observations, suggestions and comments that were used to improve the *ex ante* assessment. The following general recommendations were received during these group exercises.

Table 3.2 INIFAP suggestions and comments[24] about the preliminary model

Cheese Cooperative
• *Evaluate the feasibility of a community goat producers' association to reduce producers' economic vulnerability.* • *Allow the association to maximize benefits of an "economy of scale" due to increasing production and decreasing production costs over time.*
Aged Cheese Market
• *Add structure to test the feasibility of market expansion beyond Xico (e.g., Coatepec and Xalapa markets, distant national markets, and export markets).* • *Add structure to evaluate the impact of market limitations due to niche market saturation on the profitability of goat operations.* • Expand market structure based on microeconomic literature. • Evaluate the impact of price elasticity on supply and demand. • A market based on "perfect competition" causes producers to become "price takers," which tends to worsen their economic situation in the long-term. • Production must be well regulated to avoid market saturation. • The price of aged cheese is highly unstable in conditions of "perfect competition."
General Comments
• *Estimated parameter values should be reevaluated based on sensitivity testing and the revision of existing literature.* • *Increase emphasis on seasonal production and market trends.* • *Justification of key assumptions in the model is necessary.* • Some variable names are difficult to interpret (e.g., reference values). • Better explain the influence of model variables and components on other components to aid in understanding. • Focus on an individual household rather than the aggregated community. • Understand actual conditions in the community so that the model is a closer approximation to reality. • It is difficult to evaluate producer expectations, perceptions, and goals, especially in a highly uncertain climatic and market environment. • Model is useful to evaluate behavioral trends and implications for goat farmers given different production scenarios.

[24] The recommendations in italics were subsequently incorporated into the model.

Goat Production
• Include parameters to represent the influence of improvements in animal infrastructure (e.g., corrals, sheds, feeders, and waterers). • Better represent goat health and nutrition and their effects on flock performance.

3.2 Policy Analysis: Value-Added Cooperative Model Implications, Simulated Interventions and Shocks

This policy analysis assesses *ex ante* the feasibility of value addition in Micoxtla, Veracruz, Mexico. The overall objective is to evaluate cooperative potential to increase the profitability of Micoxtla caprine operations. Thus, instead of maximizing profit, the goal of the hypothetical cooperative, and of this *ex ante* impact assessment, is to increase the profitability from raw milk sales and dividend payments. The likelihood of cooperative success is also assessed under different cooperative management policies, market conditions, and external shocks. The reference mode graph, profitability of the aggregate community flock in Micoxtla, is used as the primary indicator of economic benefits. Cooperative cash holdings and cancelled cheese orders are also used to assess cooperative capacity to fulfill the overall objective.

Parameter values used in the model for the baseline simulation are shown in Table A2.3. Most parameter estimates[25] are based on information compiled during the INIFAP-led micro-watershed development project. This information consists mostly of survey data, measurements and observations by INIFAP workers, and INIFAP expert opinions. Best unbiased parameter value estimates were derived from this information. All model parameters were tested in a comprehensive sensitivity analysis (Section 3.2.6).

[25] Parameters associated with the proposed cooperative and the market for aged cheese are unknown and were estimated with a higher level of uncertainty.

Reported summary data for each simulation (Table 3.3) include: the simulation name, cumulative profitability of Micoxtla caprine operations, cumulative dividend payments, total cancelled orders for aged cheese, and approximate cooperative solvency time.

Table 3.3: Policy Analysis Simulations Summary Table

Simulation Name	Cumulative Profitability (Millions of Pesos)	Cumulative Dividend Payments (Millions of Pesos)	Cheese Orders Cancelled	Coop Solvency Time
Base	0.906	0	N/A	N/A
Cooperative	1.930	0.943	10,619	2011
Optimal Market Size (137 potential buyers)	3.397	2.183	118,069	2012
Optimal Milk Payment Price	1.944	0.656	11,092	2013
No Payment for Raw Milk	1.890	2.201	10,549	2010
Optimal Milk Price No Dividends	1.703	0	15,409	2011
2017 Dry Season Demand Shock	1.886	0.902	9,648	2011
2017 Rainy Season Demand Shock	1.897	0.913	9,957	2011
2017 Dry Season Cheese Price	1.870	0.886	11,180	2011

Simulation Name	Cumulative Profitability (Millions of Pesos)	Cumulative Dividend Payments (Millions of Pesos)	Cheese Orders Cancelled	Coop Solvency Time
Shock				
2017 Rainy Season Cheese Price Shock	1.863	0.879	11,299	2011
2010 Drought Shock	1.914	0.935	10,470	2010
2017 Drought Shock	1.912	0.947	10,332	2011
Combined 2019 Market and 2017 Drought Shock	1.864	0.898	9,428	2011

3.2.1 Baseline

As a point of departure, historical and projected future patterns of behavior over time were simulated in the baseline simulation. Micoxtla animal and milk production patterns continue as they have historically[26] without cooperative operations, meaning that average caprine income is low and characterized by substantial seasonal variation. The graph of monthly profitability over time (Figure 3.3) is the simulated equivalent to the continuation of the *status quo* in the reference mode graph (Figure 2.2).

[26] Model parameter values for the historical simulation are located in Table A2.3.

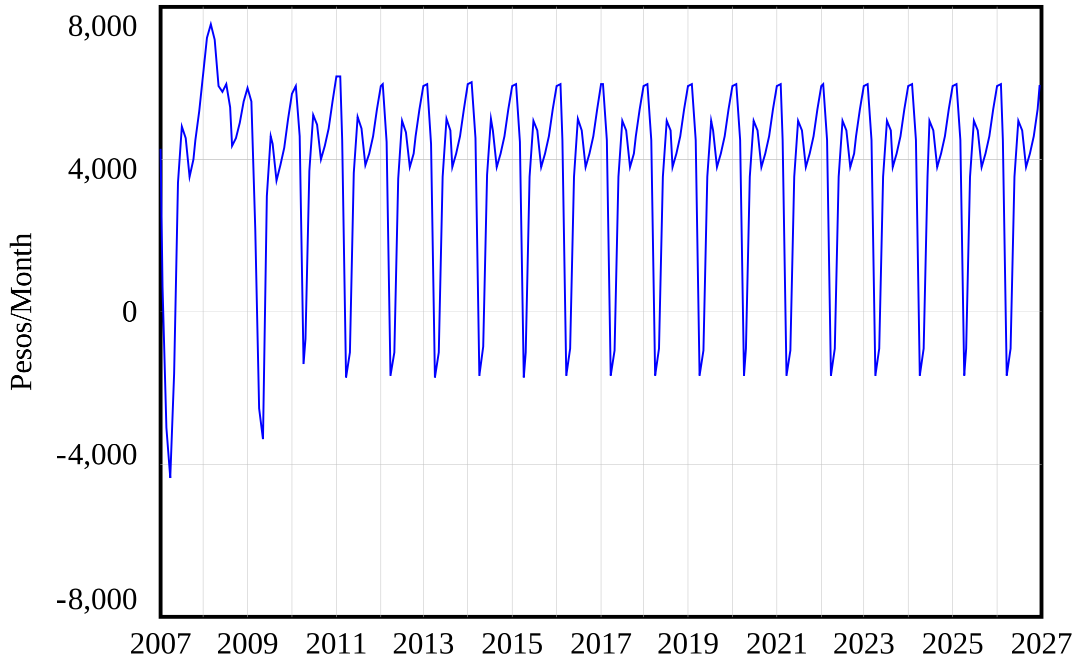

Figure 3.3 Simulated monthly profitability of community caprine operations. The base simulation assumes goat production and milk marketing continue as they have historically.

The simulation begins during the dry season in January 2007. Oscillatory behavior is observed due primarily to fluctuations in forage availability from seasonal rainfall (Figure 2.6). The seasonal forage production pattern exogenously induces oscillations in all results. It directly affects flock size and flock profitability via nonlinear effects on the rates of birth, culling, adult doe death, and milk production. The simulation results are also influenced by seasonal fluctuations in the price of raw milk (Section 2.3.3.2.8). Many initial stock and parameter values are chosen so that the model would initialize in dynamic equilibrium without exogenous disturbances (e.g., rainfall and milk price). Therefore, the oscillatory pattern is also constant and repetitive as endogenous feedback mechanisms continually adjust to forage productivity patterns, which are proportionately affected by historical seasonal rainfall patterns.

The base simulation is consistent with traditionally low net margins reported by Micoxtla caprine producers. Due to limited milk production during the dry season, community caprine activities are not profitable for a period of about two months (April and May) each year. The size of the community goat herd oscillates around approximately 125 adult does. The simulated cumulative net margin of the community goat herd during the 20 year time horizon (2007 to 2027) is about $905,000 pesos, primarily from sales of milk, *cabrito*, and culled animals (Figure 3.4). Milk is the most important, accounting for 78% of total income, followed by sales of *cabrito* (19%) and culled goats (3%). This distribution qualitatively approximates the *status quo* for caprine activities in Micoxtla (INIFAP, 2006b).

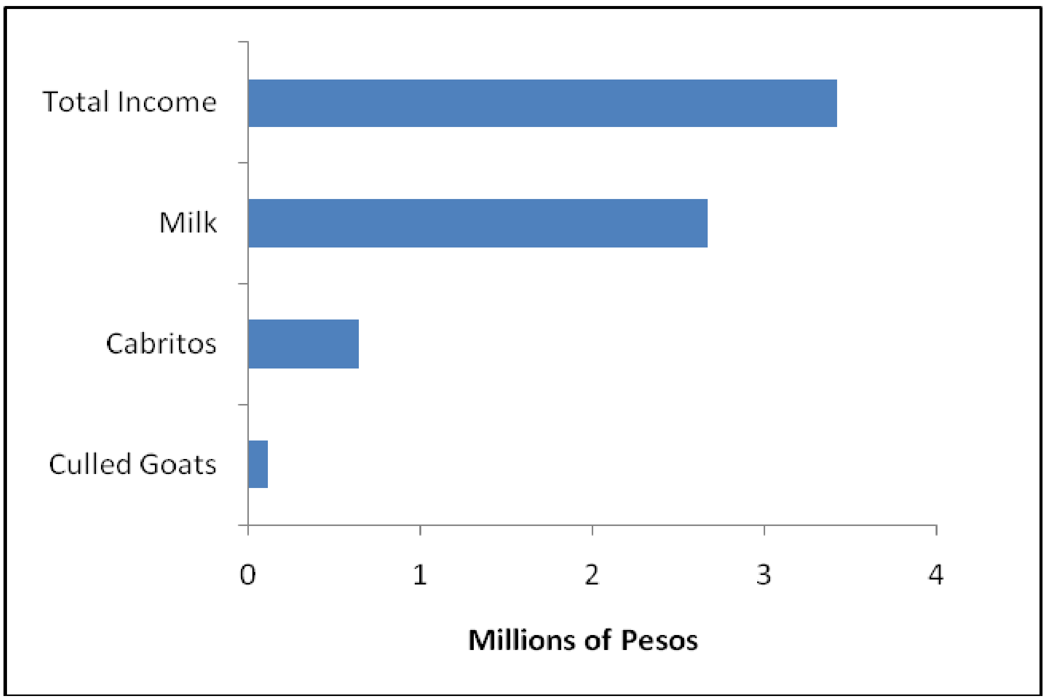

Figure 3.4 Income generating activities from caprine activities in Micoxtla (base simulation). Values are cumulative over the model simulation.

3.2.2 Aged Cheese Cooperative Feasibility

An aged cheese cooperative managed by Micoxtla caprine producers is one proposed option to augment household income. This *ex ante* analysis assesses the feasibility of the cooperative to achieve the objective of raising household profits from caprine operations. In contrast to the simulated baseline behavioral pattern (Figure 3.3), cooperative operations (Figure 3.5) create a goal-seeking behavioral tendency in the monthly profitability of community caprine activities from 2011 to 2015 until achieving a sustained pattern of oscillation at greater average profitability. The qualitative shape of the oscillations also changes between the base and cooperative simulations due primarily to cooperative dividend payments.

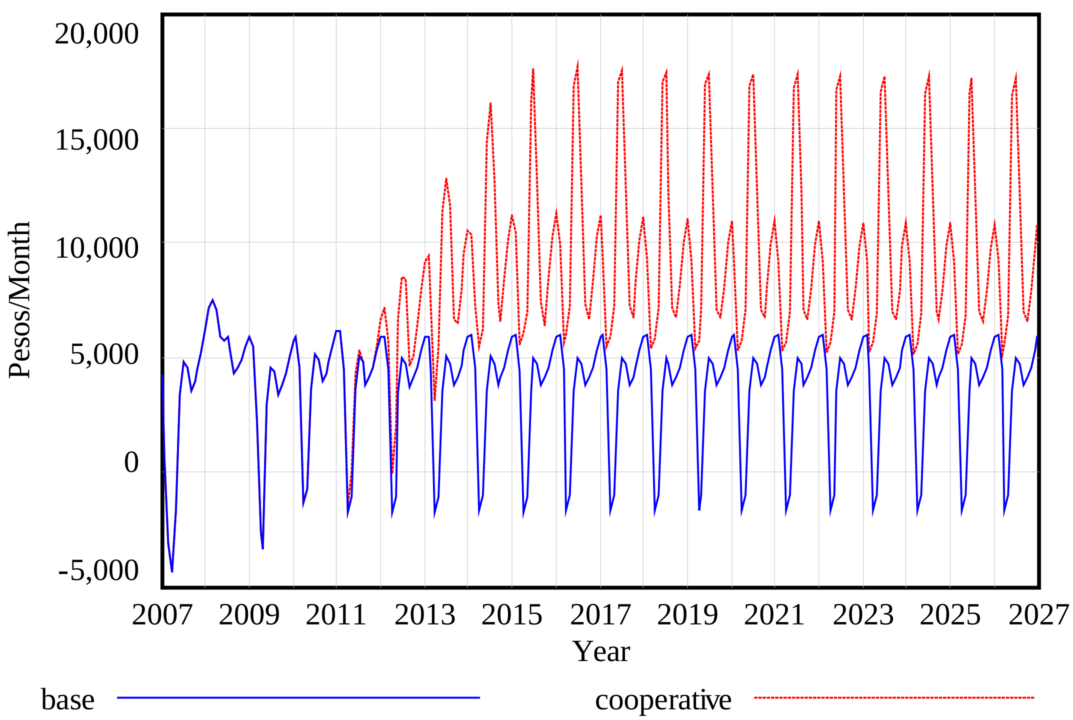

Figure 3.5 Monthly profitability of community caprine operations. The base simulation is compared to the cooperative simulation.

The differences between the base and cooperative simulations affect numerical, behavioral, and policy sensitivity in simulation results. In the cooperative simulation, aged cheese market structure is exogenously activated two years after the simulation start time when marketing work is simultaneously initiated by INIFAP. This produces an S-shaped growth pattern in the number of buyers and in the consequent demand for aged cheese over time (Figure 2.10). A small exogenous investment in cooperative productive capacity is made simultaneously with initial marketing work. Hereafter, cooperative capacity investments are made endogenously in response to the market demand for aged cheese in Xico. Once production capacity is established, the cooperative begins buying and processing fluid milk from Micoxtla farmers for the local market price. Cooperative productive capacity, market demand, or milk supply can limit the quantity of milk processed by the cooperative. Limitations are dependent on season and simulation time.

Oscillatory goal-seeking behavior in the monthly profitability of caprine activities ensues as the cooperative becomes solvent and is able to distribute dividends on a seasonal basis. The initial solvency point, defined as the time when cooperative operations become profitable and dividends can be distributed to participating farmers, is normally reached after the startup period. However, cooperative policy is to first fulfill desired capacity investments before distributing dividends (Section 2.3.3.2.7).

Thus, the base and cooperative simulations begin to diverge in 2011, more than two years after cheese manufacture begins. Production and sales delays in the cheese supply chain prevent cooperative solvency from occurring earlier. The monthly profitability of community caprine activities reaches its maximum values by 2015 when the market demand for aged cheese seasonally limits further growth. Seasonally shifting feedback dominance allows this behavior to occur. The exogenously imposed seasonal rainfall pattern limits milk production during a portion of each dry season. Rainy season milk supply is constrained by the size of the adult doe flock[27] and by milk productivity. The relationships between forage availability and the rates of milk productivity, birth, death, and household milk consumption are present in multiple balancing feedback loops affecting dry season milk supply.

As the cooperative acquires experience, the costs of production, marketing, and storage are expected to decrease (Section 2.3.3.2.4). This allows the cooperative to decrease the price of aged cheese. Therefore, average cheese cooperative profits are slightly smaller with slightly decreased dividend payments from their maximum levels by the mid-point of the simulation.

The cumulative profitability of community caprine activities is 1,930,900 pesos ($1,025,034 pesos > base simulation) during the 20-yr time horizon. Similar to the baseline simulation, the principal sources of profit are from the sales of culled goats, *cabritos*, and milk[28] (Figure 3.6). Milk is the most important source of caprine profits in both the base and cooperative simulations. Forage costs are subtracted from the aforementioned sources of income to calculate total profits during the 20-yr time horizon.

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[27] Flock size is affected by the rates of culling and doe purchase, which are both management variables that are adjusted based on profitability. The only option for reinvestment of profits in the current model version is the purchase of adult does.

[28] In the cooperative simulation, milk profits include milk sales in both Xico and to the cooperative.

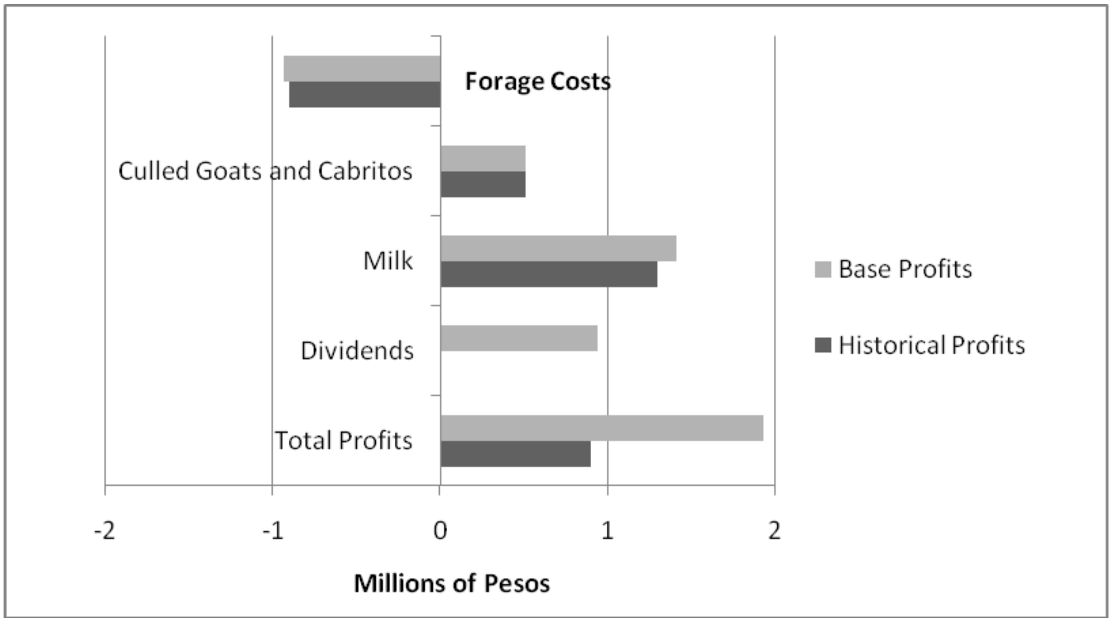

Figure 3.6 Breakdown of cumulative community caprine profits from the baseline simulation and the cooperative simulation.

Milk is the most important income source for Micoxtla goat farmers until the cooperative becomes solvent and can begin distributing dividends (2011). During 2012 and beyond, dividend payments become the most important income generating activity on a seasonal basis. Milk, culled goat, and *cabrito* income patterns are relatively consistent throughout the simulation. Forage costs are also seasonally consistent. Therefore, the principal difference between monthly profitability in the base and cooperative simulations is the additional earnings from cooperative dividend payments (Figure 3.7).

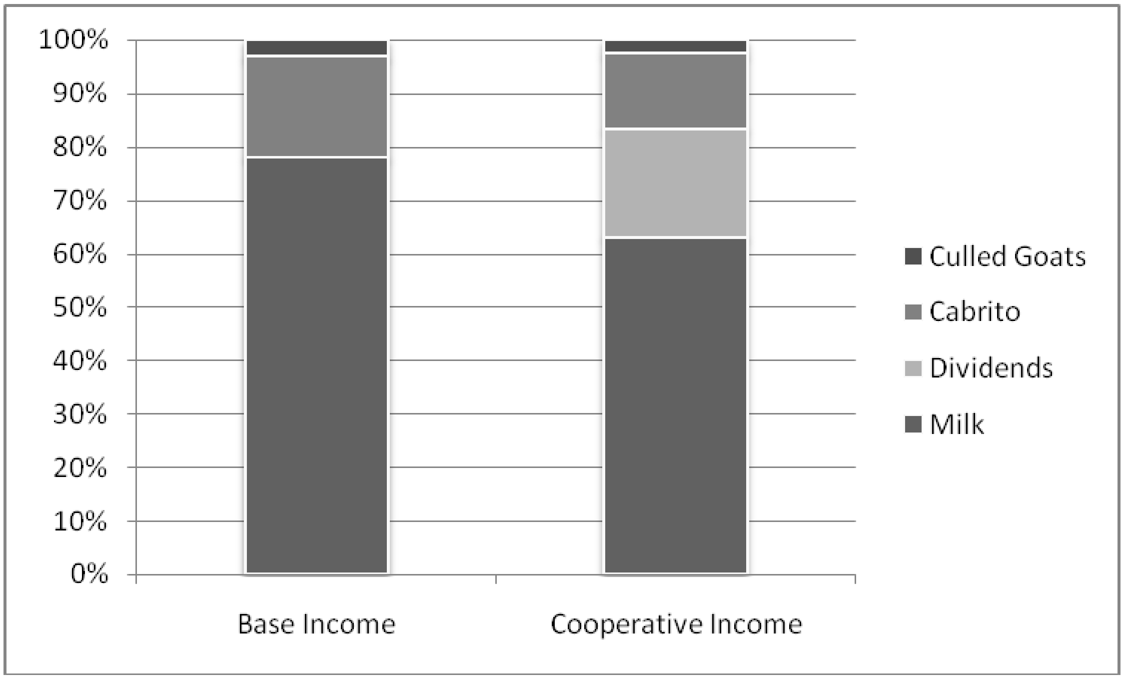

Figure 3.7 Income generation activities affecting monthly profitability. Each is displayed as a percentage of total income for the base simulation and the cooperative simulation.

In the base simulation, income generated by the sale of raw milk constitutes almost 80% of total income. Similarly, milk and dividend receipts comprise just over 80% of total income in the cooperative simulation. Total income contributions from *cabrito* and culled goat sales decrease slightly as a consequence of overall higher income levels. The importance of dividend payments from the cooperative is indicated by disaggregating the monthly revenues earned from the two principal income generating activities for Micoxtla goat farmers (Figure 3.8). A three-yr outtake (2019 to 2022) from the time horizon is selected for observation of seasonal income variations.

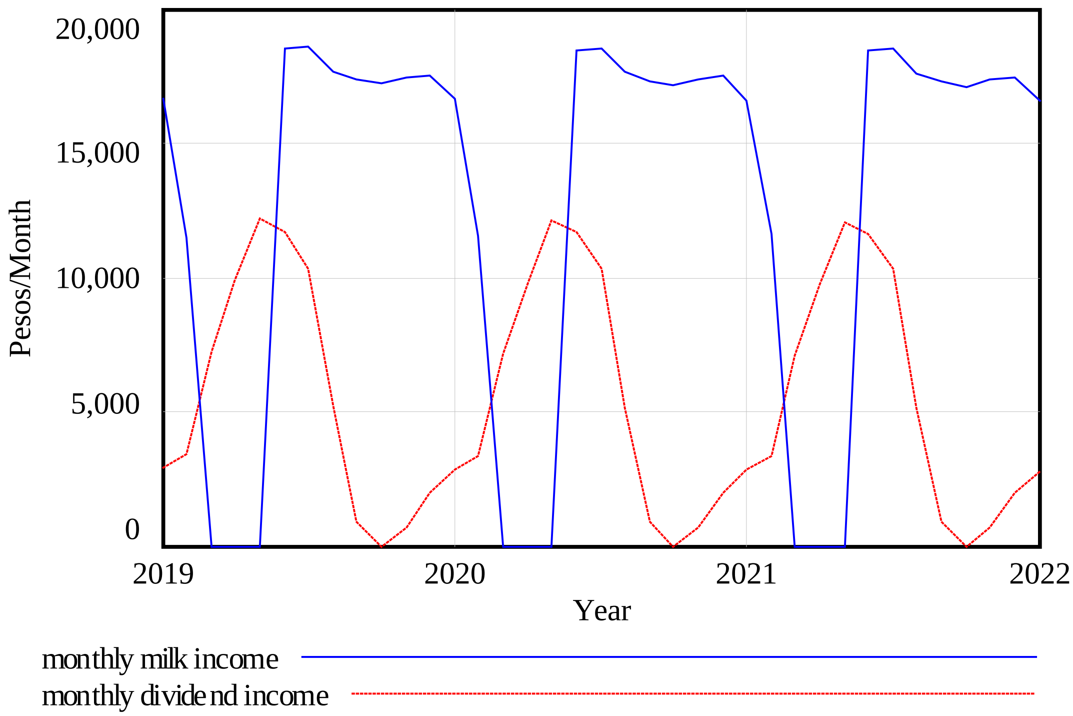

Figure 3.8 Principal income generating activities (milk sales and dividends) that affect monthly profitability of community caprine activities in the cooperative simulation. A three-year excerpt from the time horizon displays seasonal variations.

Dividends are important sources of income diversification that permit higher continual returns from caprine activities. As a result of delays in cheese manufacture and sales, most dividend payments occur during the dry season (Figure 3.8) when milk production and sales, and *cabrito* and culled goat sales diminish. These dividend receipts provide a source of income during the dry season when Micoxtla caprine operations typically incur losses for a period of about one month (Figure 3.3). Non-caprine sources of agricultural income are also low or absent during the dry season.

After cooperative solvency is attained, the least profitable point in the cooperative simulation is approximately equal to the most profitable point in the base simulation (Figure 3.5). Goat producers benefit because caprine operations are profitable throughout the entire year.

Cooperative ability to make dividend payments depends on its solvency. In addition, the pronounced seasonal difference in dividend payments after the cooperative reaches solvency is a product of seasonal profitability trends in cheese production. The profitability pattern (excluding dividend payments and capacity investments) of the cooperative (Figure 3.9) is also seasonal.

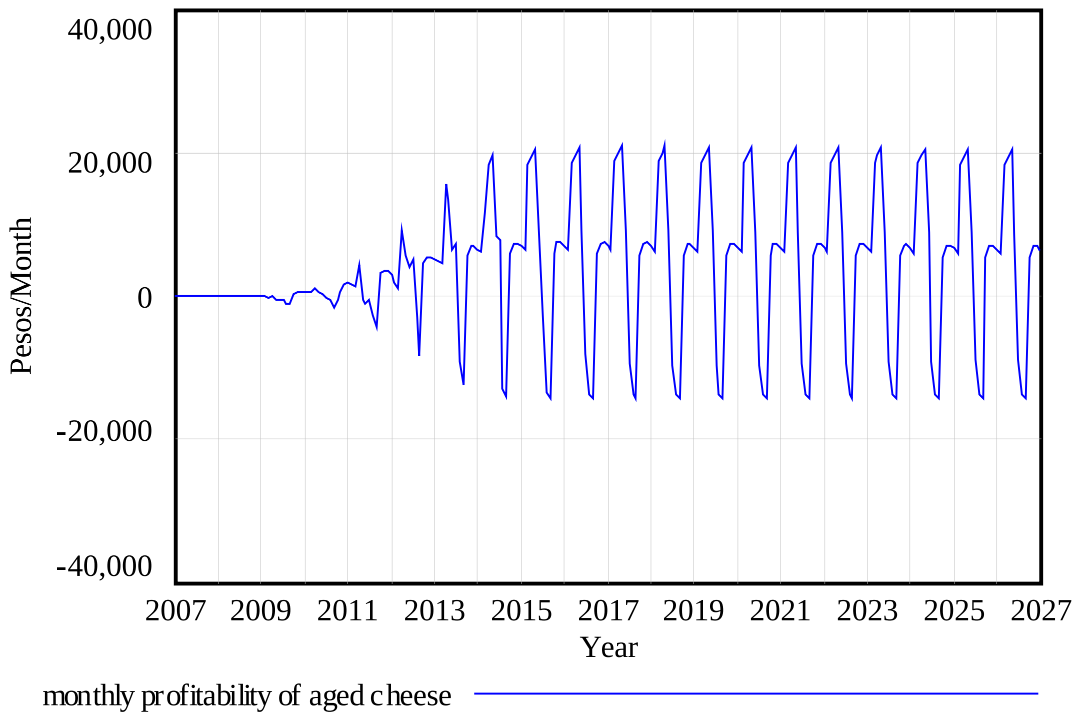

Figure 3.9 Profitability of the cheese cooperative in the cooperative simulation, excluding dividend payments and cooperative capacity investments.

The cooperative incurs losses during each yearly period slightly longer than three months from mid-May to mid-August. This occurs due to limited or absent milk production during the dry season. As a result, cheese production ceases during a short period of the dry season. Inertia in the system permits accumulation of cheese production and storage costs when the aged cheese inventory is exhausted. A similar behavioral pattern is observed in the cash balance of the cooperative (Figure 3.10), which also includes deductions from cooperative management policies (cheese processing capacity investments and dividend payments).

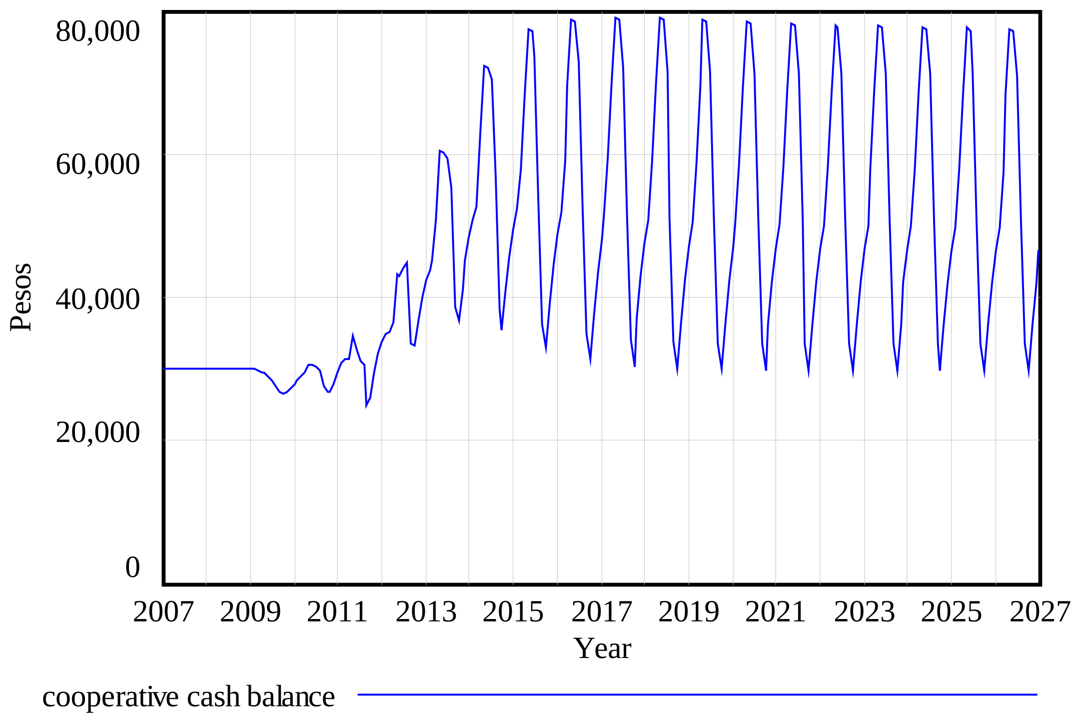

Figure 3.10 Cash holdings of the aged cheese cooperative in the cooperative simulation.

The initial cash holding of the cooperative is $30,000 pesos (Figure 3.10), an arbitrary value representing the initial cash investment in the cooperative. The performance of the cooperative, displayed as cash holdings, oscillates over time due to the cooperative management policy (Section 2.3.3.2.7 and Appendix 2, Table A2.3, Part D), and the seasonal profitability trends of aged cheese production and sales discussed above. The seasonal absence of cooperative cheese production due to insufficient supply of milk prevents the cooperative from fulfilling its cheese market orders (Figure 3.11).

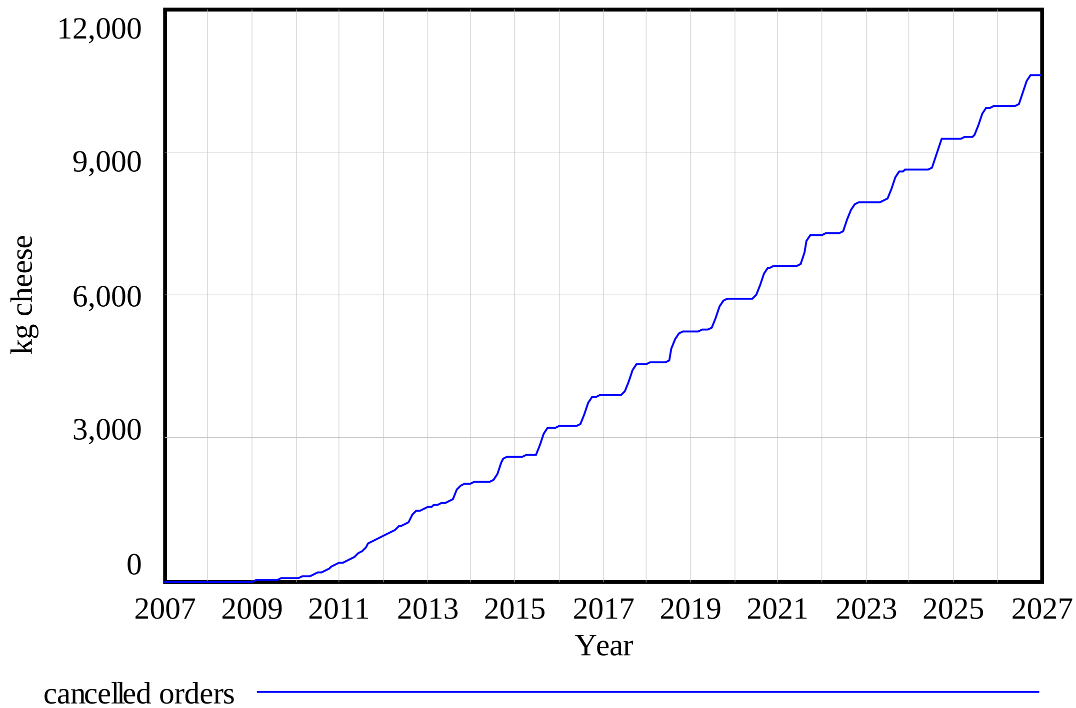

Figure 3.11 Cumulative cancelled orders for aged cheese, cooperative simulation.

In this analysis, it is assumed that cancelled orders do not affect market demand. However, the cooperative's inability to meet the market demand for aged cheese may be a critical limitation to cooperative success because cancelled orders signify opportunity losses in cheese sale income. Cooperative and producer profit margins could be improved by stabilizing milk and cheese supply throughout the year. Within 42,700 kg total orders for cheese, over 10,600 kg are unfulfilled during the 20-yr horizon. This represents a cancelled order rate of almost 25% and approximately

$1,200,000 pesos of lost income[29]. A priority for future model versions is the incorporation of feedback structure that adjusts market demand and customer satisfaction according to cancelled orders.

The cooperative simulation suggests that an aged cheese cooperative could be successful in improving farmer profits from caprine operations. However, this depends on the ability of the cooperative to become profitable and solvent in a timely manner in order to begin redistributing profits to participating farmers. Further implications of cooperative management strategies on farmer profits and cooperative success will be evaluated in Section 3.2.4.

3.2.3 Initial Market Size

The aged cheese market size is another factor that could affect the profitability of goat operations. The default population of total potential buyers is 30, although not all potential buyers become actual buyers in the market. The number of actual buyers directly determines the market demand (Figure 2.10), which affects desired production capacity. An optimization test[30] evaluates the market size that would provide the greatest cumulative profits for goat farmers under default cooperative simulation conditions. The market size is varied between 0 and 200 buyers while all other model parameters are held constant. The optimal number of total potential buyers was 137. The

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[29] This calculation assumes an average aged cheese price of 113 pesos/kg, the approximate average price for aged cheese during the cooperative simulation.

[30] All policy optimizations are completed using the Vensim optimization function.

cooperative simulation and the optimized market size simulation are displayed (Figure 3.12).

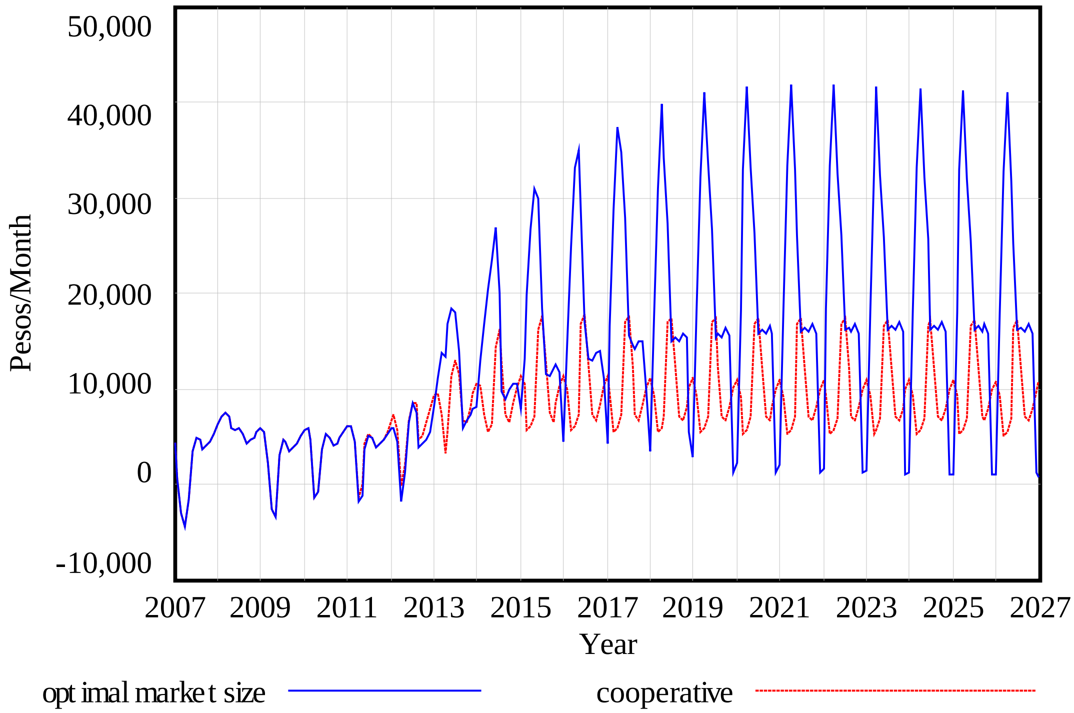

Figure 3.12 Monthly profitability of community caprine activities with different potential market sizes. The cooperative (30 potential buyers) and optimal market size simulations (137 buyers) are displayed.

If the market size increases beyond approximately 130 potential buyers, milk production capacity can become limiting year round rather than only during and after the dry season. The cheese cooperative would risk losing buyers due to its increased inability to fulfill the market demand, although it is never able to meet the market demand during periods of seasonally low milk production (Figure 3.12). Although the optimization test suggests an ideal market size of 137 potential buyers given production capacity constraints, the optimum market size given the current milk production capacity is between 110 and 120 buyers, beyond which the added returns are minimal because production capacity reaches its maximum levels. In addition, the amplitude of seasonal profitability oscillations increases with market size. For example, higher market demand permits increased profits during the rainy season. However, limited milk supply during the dry season lowers cheese production, and further increases the amplitude of profitability oscillations. This added instability and uncertainty in income could be disadvantageous for farmers. In addition, the number of cancelled orders increases to much higher levels when the market size is larger, thereby increasing the risk of eroding buyer confidence. The percentage increase in cancelled orders more than doubles the percentage increase in potential buyers, which indicates reduced marginal benefits from further expanding the market base.

Milk production capacity is only able to meet the cooperative demand for milk during the rainy season. Thus, most cheese sales take place during the dry season. The benefits of increasing the market size are not extremely evident because cancelled orders (Figure 3.13) increase yearly during and after the dry season due to limited or absent milk production. This suggests the need to stabilize milk production throughout the year. As an alternative, the cooperative could begin to purchase and process raw milk from producers in other communities. Milk production could also be stabilized by storing excess forage during the rainy season for dry season feeding, and buying additional forage or feed to cover remaining feed deficits. These production management options are beyond the scope of this analysis, but should be considered by INIFAP as potential cooperative extension services to improve the quantity and quality of year-round milk production.

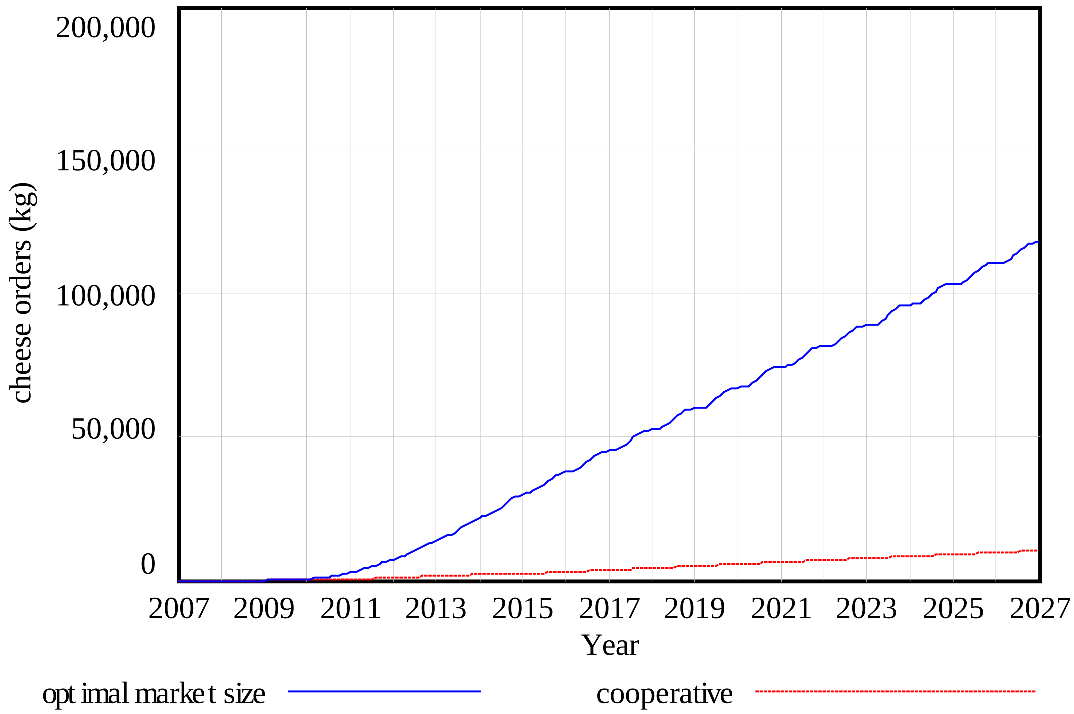

Figure 3.13 Cumulative cancelled orders for aged cheese given different potential market sizes.

A larger market makes successful cooperative management more difficult as a consequence of greater variation in seasonal cash flow (Figure 3.14). The default cooperative management policy is unable to prevent negative cash flow due to the magnitude of seasonal fluctuations in milk supply and sales. Cooperative policies (i.e., cost coverage time, dividend disbursement time, and desired cash holdings) do not respond rapidly enough and losses are incurred. Although the assumption is made that cooperative losses can be compensated in some way (e.g., grant, gift, or loan), in reality the cooperative may be unable to recover from these losses and could go bankrupt. This suggests the need for a more conservative management policy when the market size is larger. For example, for the optimal market size (137 buyers), cost coverage time must be increased from two to seven months to prevent negative cooperative cash balances. However, the cumulative profitability of community caprine activities also decreases by nearly $200,000 pesos because fewer dividends are paid.

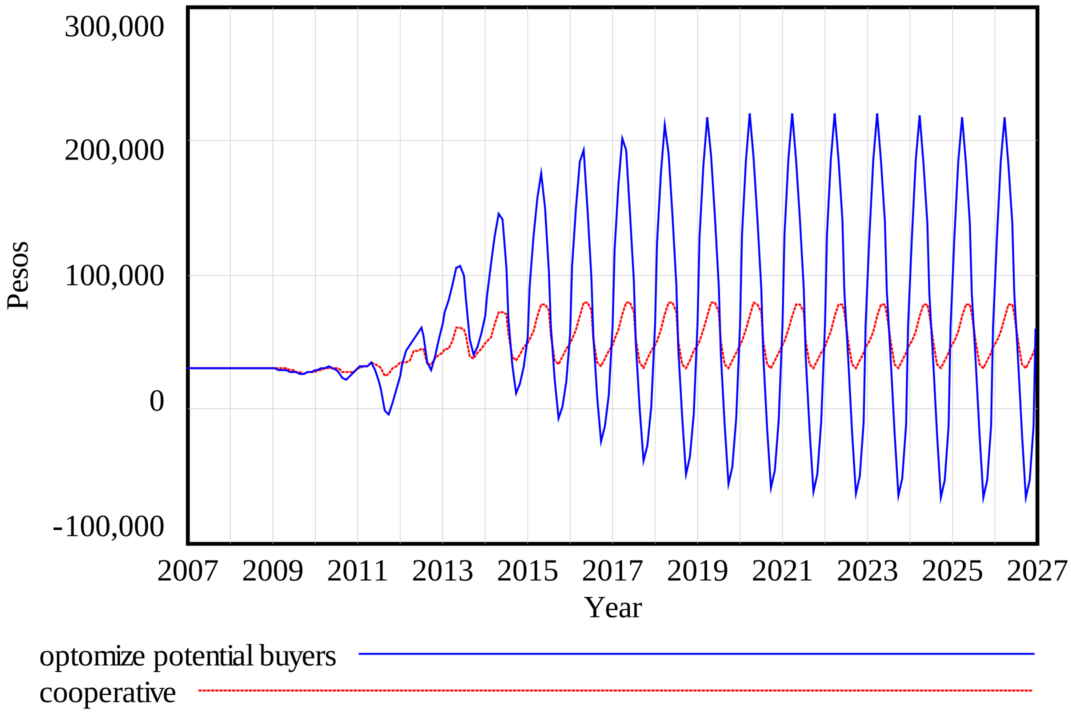

Figure 3.14 Cash holdings of the aged cheese cooperative given different potential market sizes.

3.2.4 Cheese Cooperative Management

Initial review of the cooperative simulation suggests that the cooperative does have a very strong chance of making community caprine activities more profitable. Therefore, the forthcoming analysis evaluates cooperative management options to encourage farmer participation in the cooperative and maximize short-term and long-term profitability for Micoxtla goat farmers. To assure initial participation, one strategy is paying farmers a higher price for raw milk than the actual market price in Xico. This could increase the risk of cooperative failure or result in a longer time delay before the cooperative is able to become solvent and pay dividends to farmers. Alternatively, it may be sufficient to pay the market price for raw milk to goat producers because transactions costs to transport and market raw milk are likely to be lower when producers sell milk to the cooperative (Staal et al., 1997) due to the close proximity of the proposed cooperative to the community.

There is a tradeoff between paying a higher market price to producers for raw milk and paying profit sharing dividends to producers. The objective of this analysis is to help determine an attractive way to encourage producer participation in the cheese cooperative, and later maintain that motivation through profit sharing.

In addition to the profit sharing strategy tested here, it is assumed that cooperative management aims to maintain sufficient cash on hand to either cover expected costs during the coming two months or retain a minimum of $30,000 pesos on hand. While striving to meet these conditions, the cooperative fulfills desired capacity investments and distributes dividends when feasible.

3.2.4.1 Cooperative Raw Milk Payment Strategies

To evaluate cooperative management strategies, a policy optimization test was completed using Vensim® to determine the optimum percentage above the Xico milk price that maximizes cumulative net profits for goat producers. The percentage above the market price in Xico was varied from zero (cooperative simulation) to 100%. The optimal percentage was 22.4% (4.3 to 5.5 pesos) above the Xico milk price. In addition, a separate simulation in which the cooperative does not pay producers for raw milk is included. Differences in cumulative profitability are minimal, and are numerically, behaviorally, or policy insensitive. In contrast, monthly profitability patterns are slightly policy-sensitive (Figure 3.15).

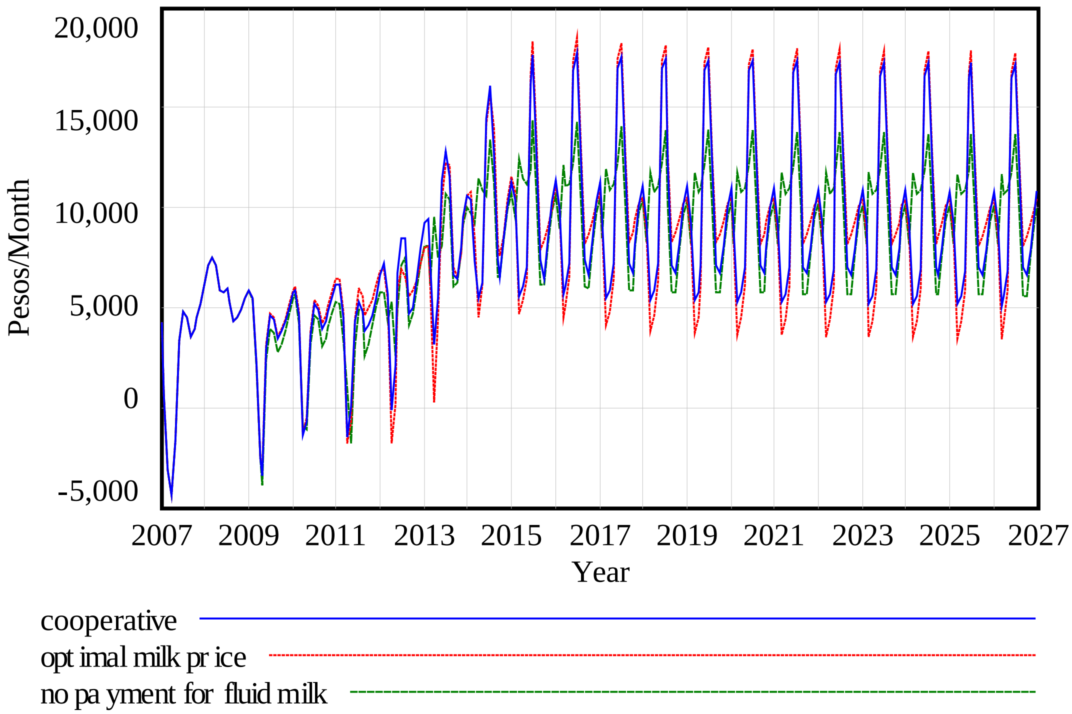

Figure 3.15 Monthly profitability of community caprine production with different milk payment strategies. Shown are the cooperative, optimal milk price, and no payment for raw milk price simulations.

The no payment for raw milk simulation represents a complete buy-in to the cheese cooperative because producers must wait until dividend disbursements begin to receive any compensation for participation in the cooperative. As a result of this policy, the cooperative almost immediately achieves solvency in late 2009, makes desired capacity investments, and is able to pay higher dividends. However, this approximately 2.5-yr delay with slightly lower milk income could be too lengthy for most farmers to withstand since this activity is one of their primary sources of income. Alternatively, loans from the cooperative or from an external source could help sustain farmers during the cooperative startup period. The most notable difference in profitability trends for the no payment for raw milk simulation is that milk production is unprofitable after the first half of 2012. This occurs because producers continue to pay milk production and marketing costs for mild sold to the cooperative but do not receive any payment for that milk, which shifts profitability oscillations (Figure 3.15).

Upon initial observation, the no payment for raw milk policy appears to be disadvantageous for farmers (Table 3.3). However, if producers are capable of sacrificing raw milk income during the cooperative startup period, it could be an innovative and beneficial long-term policy. For example, seasonal profitability oscillations shift so that the second most profitable period for goat farmers corresponds to the heart of the dry season when milk production and milk incomes reach their lowest levels. Normally, this is a period of financial hardship for community members. In contrast, the time period when profits from goat farming are the lowest corresponds to the rainy season when additional non-caprine forms of agricultural income are at their highest levels. Although other sources of agricultural income were not included in the model boundary, this is a potentially important secondary result of this strategy.

The greatest impact of different raw milk payment strategies is revealed in monthly dividend payments (Figure 3.16).

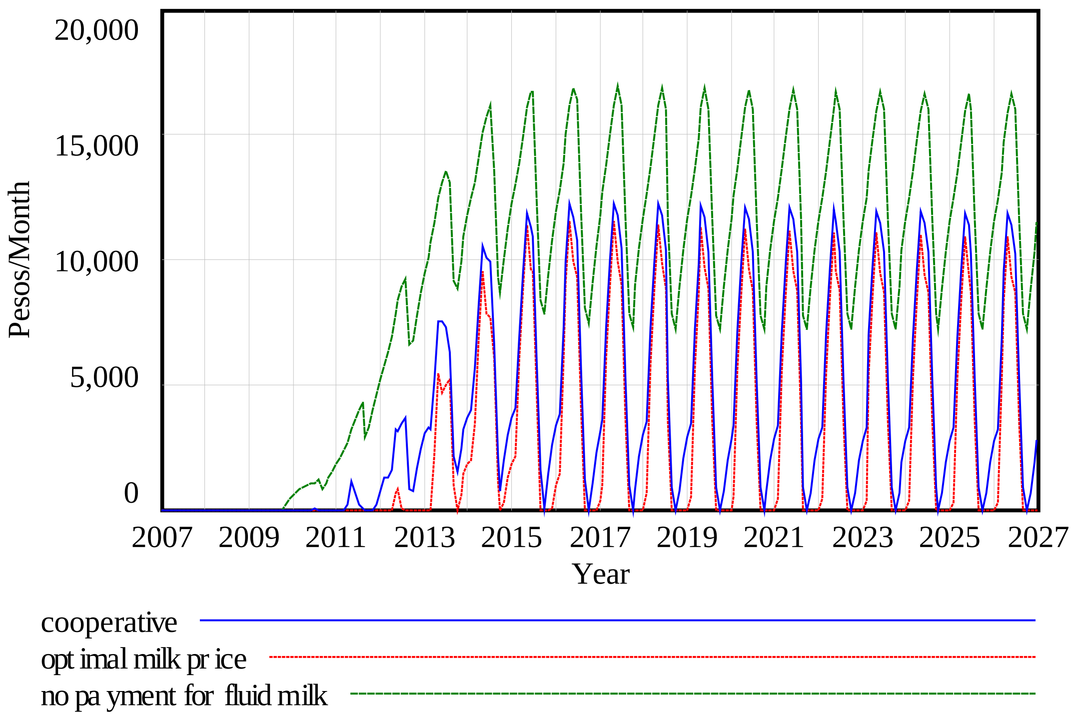

Figure 3.16 Monthly dividend payments. The three simulations display the effect of changes in cooperative payment strategies for raw milk on monthly dividend payments. Approximate cooperative solvency time can be inferred from the graph.

Although raw milk payment strategies do not affect the cumulative profitability of the aggregated caprine activities, they could have important management implications for the cheese cooperative. For example, when the cooperative offers higher prices to producers for raw milk, initial farmer participation may be encouraged. However, this action also increases the risk of failure during the enterprise startup period by increasing the time delay for the cooperative to achieve solvency, to fulfill desired investments in production capacity, and to pay dividends to producers. When farmers do not receive payment for raw milk (no payment simulation), the cooperative achieves solvency, invests in capacity, and initiates dividend payments sooner. Initial dividend payments occur approximately nine months after the cooperative initiates operations (Figure 3.16). In contrast, when the cooperative pays higher prices for raw milk (optimal milk price simulation), the time required to achieve solvency increases. In addition, the cooperative may incur losses from which it is unable to recover if raw milk payment prices are too high or cooperative profit distribution policies are too liberal.

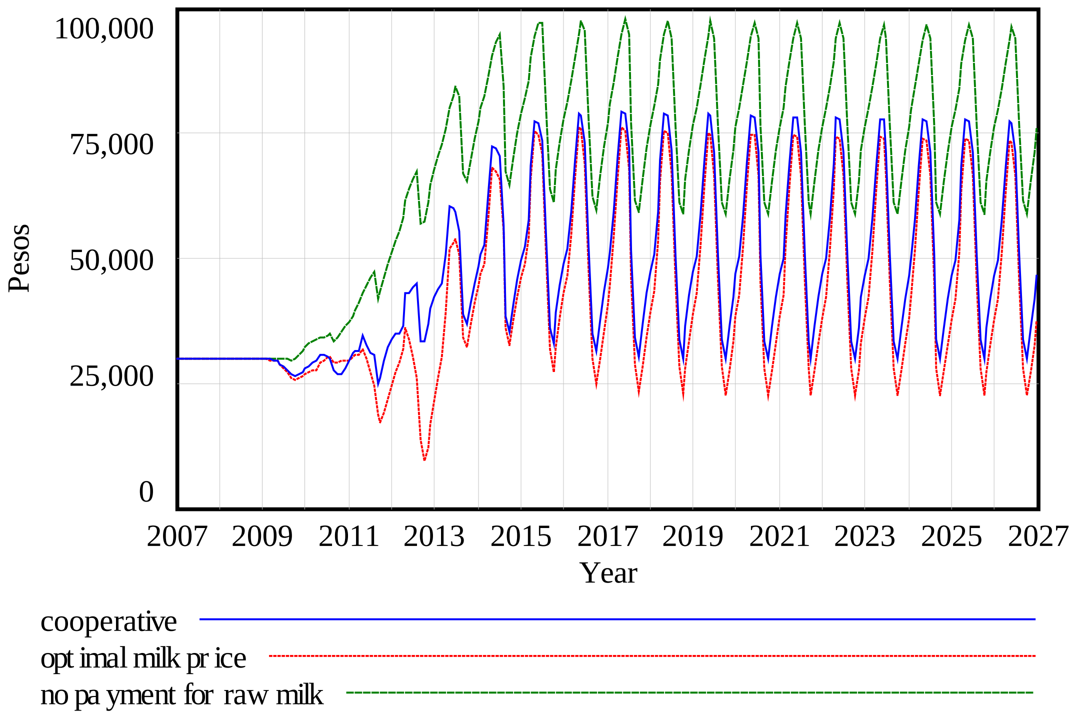

Figure 3.17 Cooperative cash holdings for three raw milk payment strategies.

The general pattern of dynamic behavior of the cooperative cash holdings is similar for each simulation (Figure 3.17): there is an initial decrease in the cash holdings as a result of delays in maturation and sales of aged cheese. Cheese production, marketing, and storage costs accumulate before cheese is sold. This is followed by a period of oscillation (brief exponential growth in the no payment for raw milk simulation) while initial investments in capacity are fulfilled. Large, sustained oscillations in cash holdings dominate the behavioral pattern for the remainder of the simulation time.

The final economic returns for producers from a combination of milk purchases and dividend payments are higher than dividends alone under the assumed cooperative payment policies (Table 3.3). However, as previously suggested, this is not necessarily the most favorable policy.

3.2.4.2 No Dividend Payments

An alternative policy for the cooperative is to not pay dividends, instead focusing exclusively on the purchase price of raw milk. Intuitively, under this strategy producer incomes would vary directly with the payment price for milk and the volume sold. However, the dynamics are altered because the primary limitation becomes the cooperative's ability to invest in its productive capacity. Consequently, the most beneficial policy is not necessarily the one with the highest milk purchase price, but a high price that also permits cooperative growth and that increases the quantity of milk purchased from producers.

A policy optimization test evaluated the variation in the percentage above the Xico milk payment price offered by the cooperative from zero to 100% (approximate prices of 4.0 to 8.0 pesos/kg). The final cumulative net gain by farmers was optimized. The optimum percentage price increase was 63.7%. For higher payment prices, the cooperative would be unable to invest in capacity, which precludes income contributions through raw milk payments (Figure 3.18).

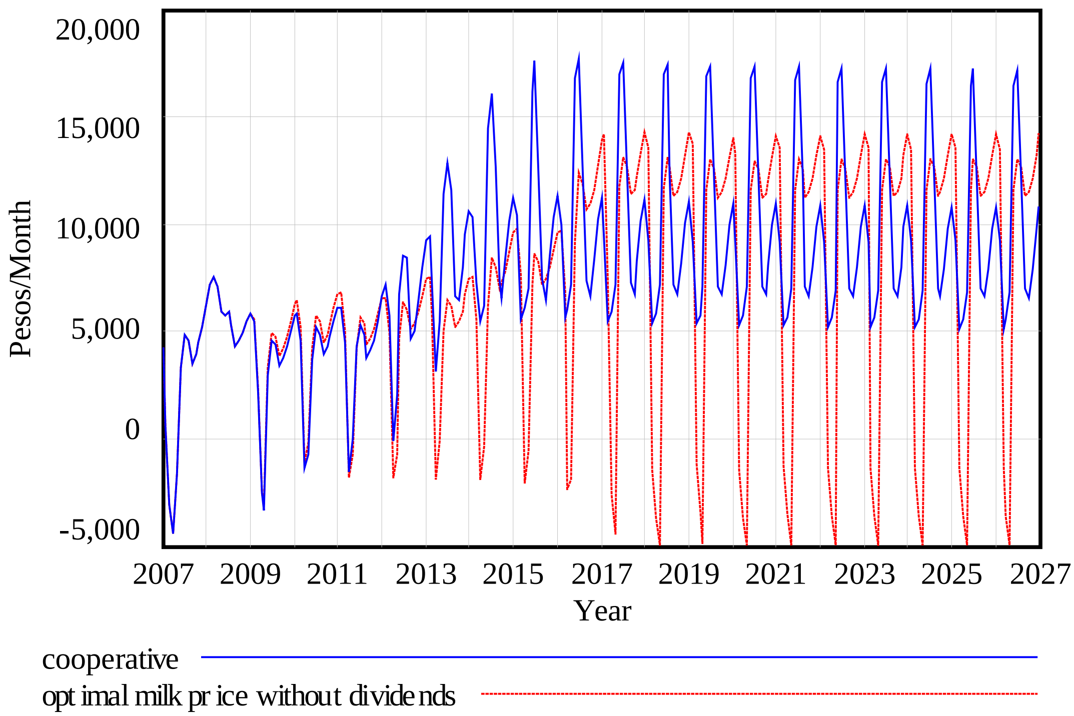

Figure 3.18 Monthly profitability of aggregate community caprine activities. The blue (solid) line represents the cooperative simulation. The red (dotted) line represents the optimal no-dividend scenario.

There is also much greater seasonal variation in profitability oscillations for goat farmers under the no dividends policy (Figure 3.18). In contrast, dividend payments help assure higher incomes that are more stable for Micoxtla farmers. Thus, the dividend payment policy is not only advantageous due to the associated higher profitability potential for community caprine operations, but it also reduces seasonal uncertainty in profitability patterns. Like the base simulation (Figure 3.3), under the optimized no-dividend payment policy, monthly net incomes become unattractive (unprofitable) during the first quarter in each year after cooperative operations begin in 2009.

The optimized no-dividend payment policy leads to negative cooperative cash balances (Figure 3.19) in the second half of 2016 and the first quarter of 2017. These losses occur because a large investment in production capacity is made in early 2016. As a result, total cooperative costs increase before additional aged cheese matures to be sold. Cash balance for the cheese cooperative drops below -$25,000 pesos during this period.

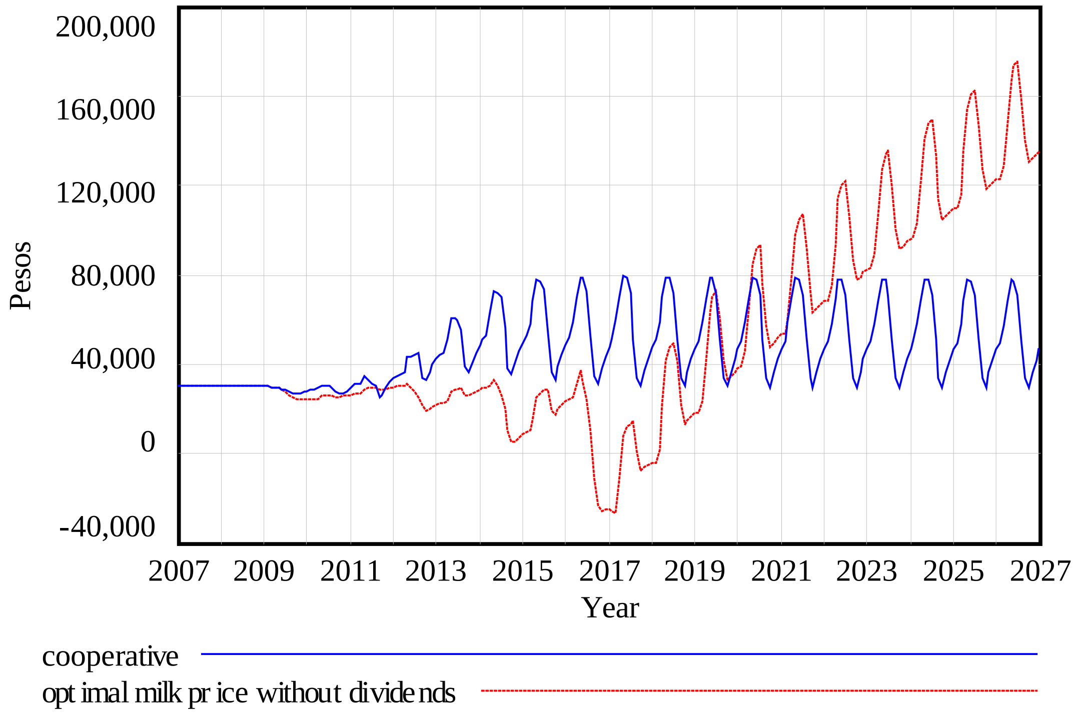

Figure 3.19 Cooperative cash holdings with optimal milk price to maximize cumulative profits from goat farming without dividend payments (blue, solid line). The cooperative simulation is also shown (red, dotted line).

Following a lengthy cooperative startup period in the optimal no dividends simulation, the cooperative achieves solvency in late 2016. Oscillating growth in the cash balance ensues after the cooperative becomes solvent. The cumulative profitability of the optimal no dividend simulation is approximately $230,000 pesos less than the cooperative simulation, thereby suggesting that a dividend payment policy may be more favorable to maximize the profitability of community caprine operations.

3.2.5 Market and Production Shocks

Market and production shocks are reasonably likely to occur in Micoxtla, and may have a large impact on the viability of the cooperative. Three shocks are tested and evaluated to assess their effects on the profitability of goat operations and performance of the cooperative. The market demand shock and the aged cheese price shock affect the market and cooperative components of the model while the low precipitation shock affects the production side of the model. In addition to the reference mode, indicators include the number of adult animals for the production shock and cooperative cash holdings for all shocks. These have been chosen to evaluate the performance of the animal production and value-added cooperative components of the model.

3.2.5.1 Market Demand Shock

A simulated six-month demand shock tests the robustness of the cheese cooperative given a temporary but significant market shock, which also provides insight about system resiliency to market uncertainty. A 200 kg/mo six-month decrease (from approximately 230 kg/mo to 30 kg/mo) in market demand for aged cheese was evaluated by simulating shock start times during the dry season and rainy season (January and July) of 2017, year 10 of the simulation (Figure 3.20). The year 2017 was chosen to evaluate cooperative response to shocks because the cooperative had become solvent with consistent oscillations in seasonal net incomes for producers.

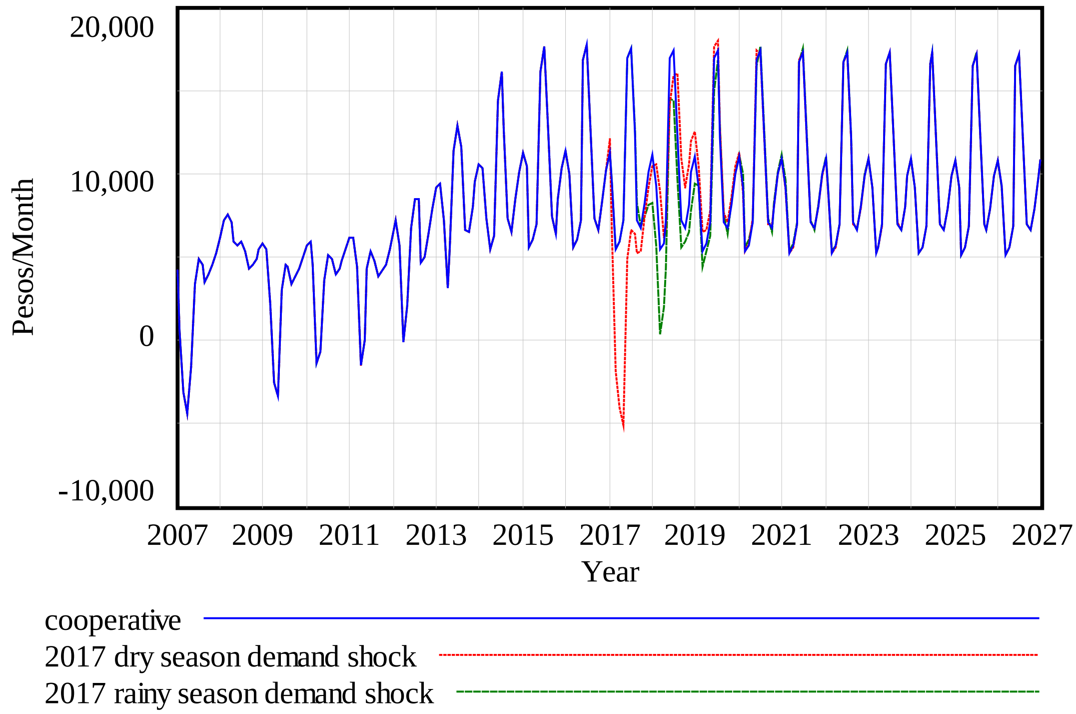

Figure 3.20 Monthly profitability of aggregate community caprine operations. The base coop simulation is contrasted with the results of the 2017 dry and rainy season demand shocks.

Approximately one-year from the time of initial shock was required for recovery. The recovery period was slightly longer than the duration of shocks because of delays in cheese production, sales, and decision making, which create a lagged inertia in the system. During recovery, monthly profitability slightly overshoots previous levels before the pre-shock oscillating pattern is recovered. The overall effect on cumulative profitability is a decline of approximately $33,000 pesos from the rainy season shock and $44,000 pesos from the dry season shock (Table 3.3). Losses accrue from a pause in dividend payments during and after the shock. However, given its magnitude and duration, total reductions in cumulative profitability from the shock are modest (2% < cooperative simulation). Cooperative management policies and other sources of income (e.g., sales of fluid milk, culled goats, and *cabrito*) partially buffer the effect of the demand shocks.

Cooperative performance in response to demand shocks was also evaluated (Figure 3.21).

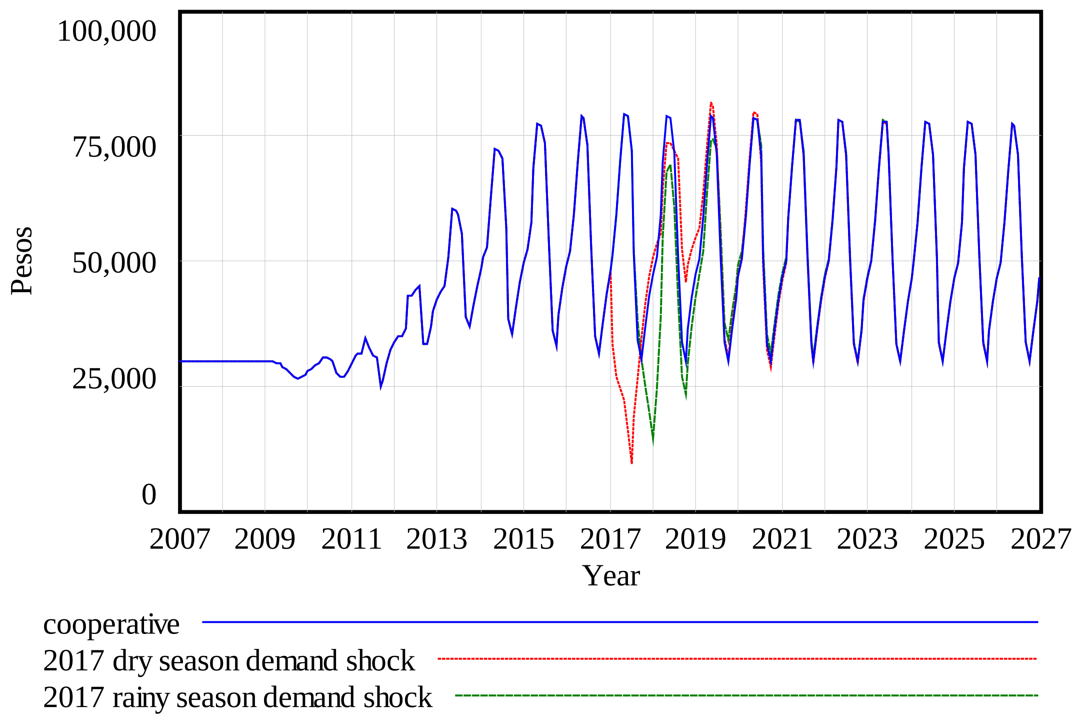

Figure 3.21 Cash holdings of the cheese cooperative. The simulations show the results of a 100 kg/mo decrease in market demand for a period of two years. The shocks begin in January (dry season) of 2017 and July (rainy season) of 2017.

The demand shock beginning during periods of low seasonal profits induced great decreases in cash holdings by the cooperative. However, although the cooperative incurs greater losses than normal, cash balance was never negative. Extreme conditions testing suggested that in order to sustain a more severe or more prolonged demand shock, the cooperative would either need to implement more conservative capacity expansion and dividend payment policies or have the ability to obtain loans during and after the shock period. Larger or more prolonged shocks are likely to cause negative cash balances or even bankruptcy. This inference was confirmed by the aforementioned extreme demand shocks, especially when the cooperative did not lower capacity utilization. Economic losses for the cooperative occur because it accumulates excess inventory and cheese storage costs during and after the shock period.

However, the cooperative survives intense and lengthy demand shocks by endogenously decreasing capacity utilization[31] in response to consumer demand during the shock period. A negative cash balance is normally prevented under this cooperative management strategy, but it also further depresses farmer incomes when capacity utilization decreases. This could lead to a loss in farmer confidence in the cooperative. Similar to the demand shock, an aged cheese price shock (Figure 3.22 and Table 3.3) is also tested by simulating a $50 pesos/kg decrease in the market price of aged cheese for a one-year period starting in the dry and rainy seasons of 2017. It lowers the market price of aged cheese from approximately $110 pesos/kg to $60 pesos/kg for the one-year shock period. The behavioral results and implications of the price shock are similar to those of the demand shock because it also directly affects profitability of the cooperative.

[31] Capacity utilization decreases endogenously when cheese demand is below cooperative supply in all shock simulations.

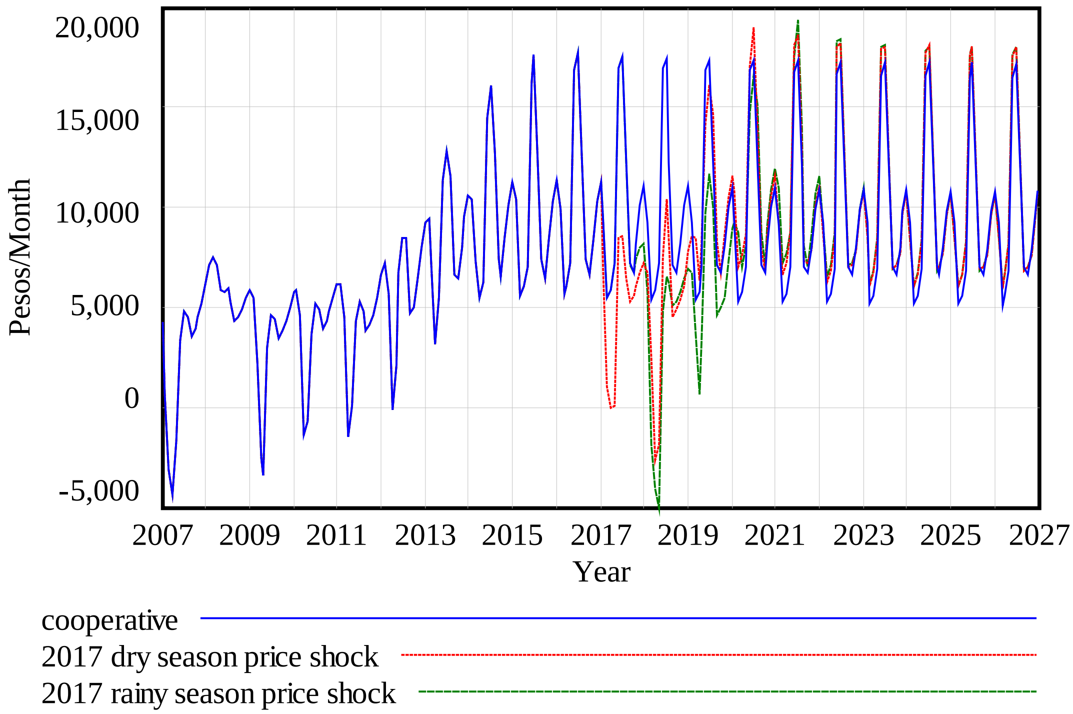

Figure 3.22 Monthly profitability of aggregate community caprine operations. The base coop simulation is contrasted with the results of the 2017 dry and rainy season price shocks.

3.2.5.2 Below-Average Precipitation Shock

Drought or below average rainfall is a continual threat to crop and forage production in Micoxtla. Low precipitation patterns, similar to the extended period of below-average rainfall from 1994 to 1996 (INIFAP, 2006a), could have a detrimental effect on forage production, the consequent success of the cooperative, and the success of community caprine production. The 1994-1996 below-average rainfall pattern[32] (Figure 3.23) is used beginning in 2010 and 2017 to test the effect for both pre- and post-solvency for the cooperative. The shock affects the goat and forage production components of

[32] As percentages of average yearly rainfall, 1994 is 92%, 1995 is 88%, and 1996 is 64% of the average. 1996 is the lowest reported yearly rainfall from the 1961 to 2002 data series (INIFAP, 2006a).

the model by simulating a historically motivated change in seasonal rainfall patterns.

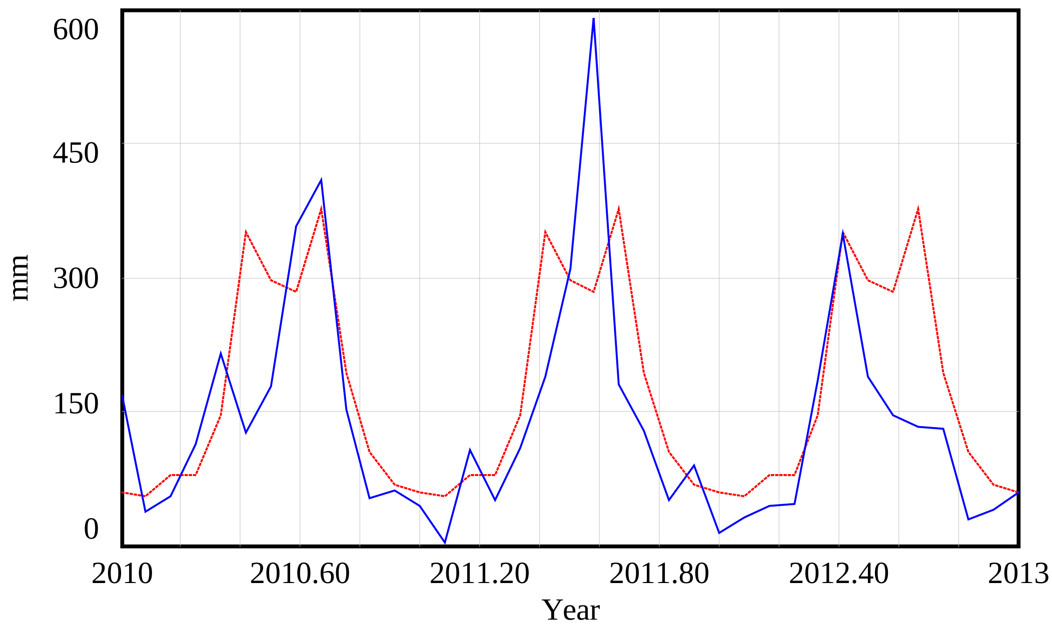

Figure 3.23 The average monthly precipitation pattern (dotted line) is contrasted with its pattern during the 1994-1996 period of below-average rainfall (solid line).

Changes in seasonal forage production are proportionate to deviations from normal rainfall (Section 2.3.3.2.2, Equation 13). However, the hypothetical nonlinear effects of producer decisions (e.g., forage land area expansion, fertilization, and decreased flock size[33]) partially compensate for forage production shortfalls. In addition to producer decisions, the nonlinear biological responses to inadequate forage resources also decrease the herd size by increasing the rates of birth and mortality, and by decreasing milk production, which are all direct determinants of profitability. Combined with producer management decisions, these simulated biological responses

[33] This management effect is in response to decreased profits rather than forage shortfalls. Management decisions decrease the doe purchase rate and increase the culling rate to decrease the herd size.

respond quickly by shrinking flock size to sustainable levels before a collapse in forage resources. This is indicative of a near-ideal management scenario. In reality, prolonged periods of below-average rainfall or severe drought would likely cause more severe economic consequences. However, the combined biological and management conditions necessary to prevent this outcome may be inferred from the modeled results. The overall effects of the shock on the profitability of aggregate community caprine operations are depicted in Figure 3.24.

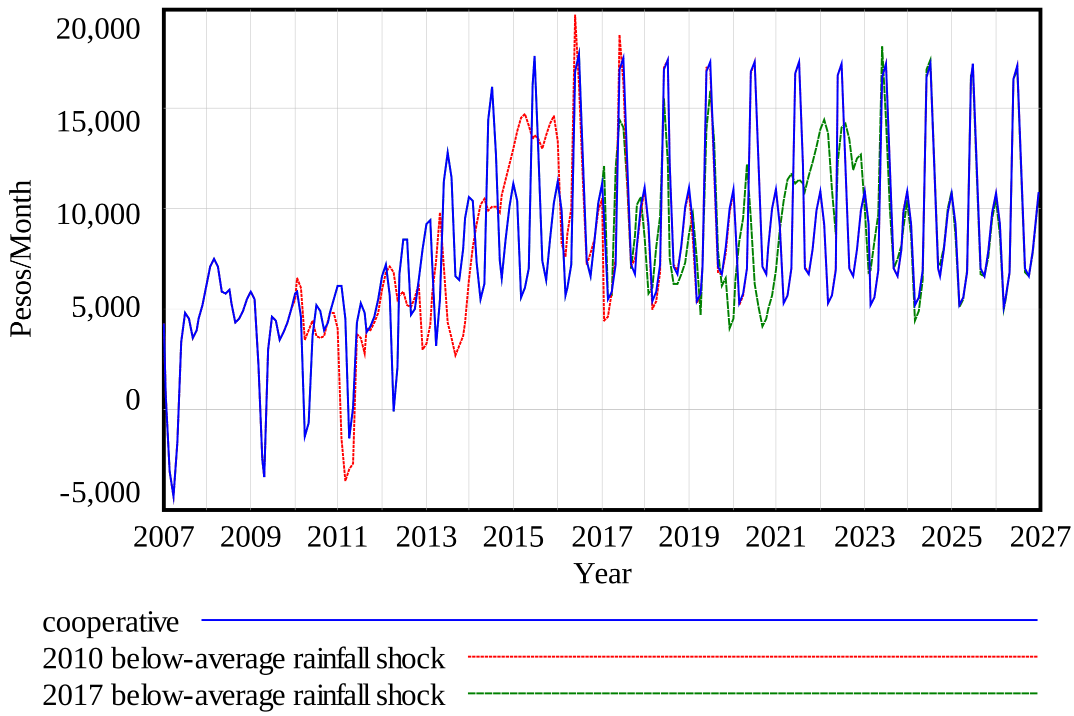

Figure 3.24 Monthly profitability of aggregate community caprine operations. The cooperative simulation is contrasted with the results of a below-average rainfall shock in 2010 and 2017.

Surprisingly, when low precipitation shocks are applied to the cooperative simulation, they do not substantially negatively affect the profitability of caprine production. Cumulative profitability only decreases by $16,000 pesos in the 2010 drought shock and by $18,000 pesos in the 2017 shock. This result is reasonable given the structure of the simulation model. Low precipitation reduces forage supply during the period of below-average rainfall. This causes the fraction of forage needs satisfied to fall below typical levels during the dry season. As a result, nonlinear effects in the model reduce the fractional birth rate and increase the fractional adult goat death rate, and the size of the adult doe flock declines rapidly during 2011 and 2013 for the 2010 shock, and in 2018 and 2019 for the 2017 shock (Figure 3.25).

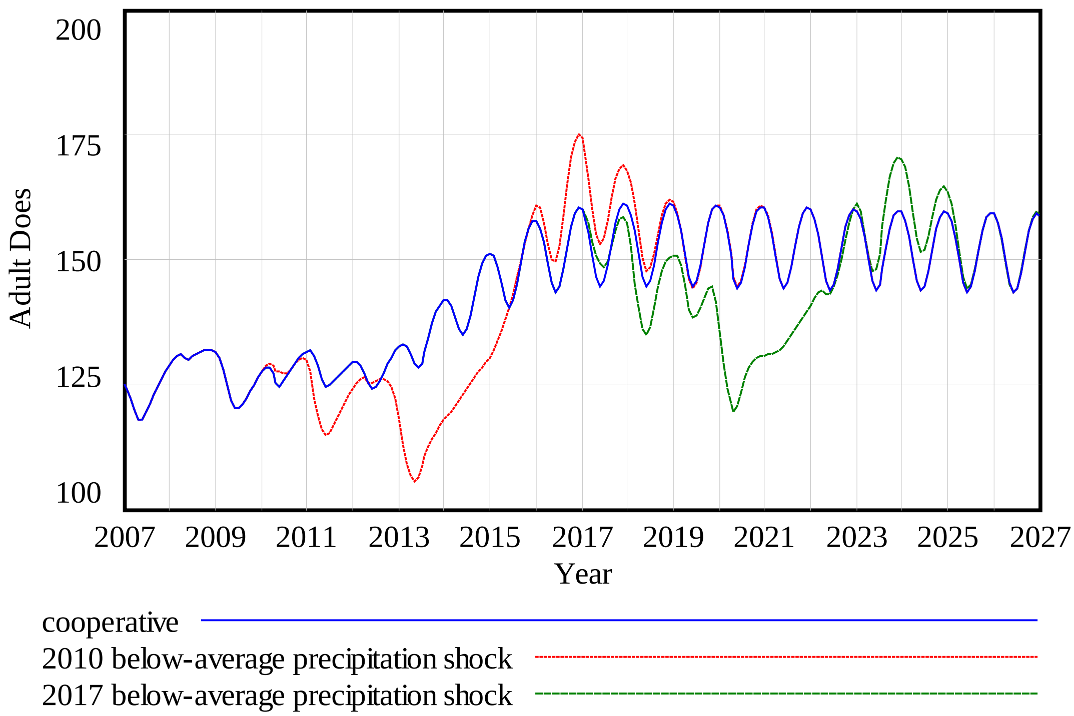

Figure 3.25 Adult does. Flock performance for the 2010 and 2017 below-average precipitation shocks are contrasted with the cooperative simulation.

The size of the goat flock declines to its lowest point in 2013 for the 2010 shock and in 2020 for the 2017 shock. Both correspond to the first post-below-average precipitation year. The stabilization of rainfall and forage production then permits the flock to begin recovery. The number of adult does decreases from approximately 125 animals to 105 animals, a 16% decrease from the 2010 shock. In contrast, during the 2017 shock, adult does decrease by 23% from 155 to 119 animals.

As flock size decreases due to the biological and decision-making responses explained above, pressure on forage resources is alleviated, thereby increasing the amount of forage available per goat. Goat health and performance improves for remaining goats after the drought shock and the flock is able to grow in the absence of forage constraints. This fosters an overshoot in the carrying capacity in 2016 (2010 shock) and late 2023 (2017 shock), approximately three years after the end of the below average rainfall period. Until forage resources become limiting again after flock size recuperates, profitability patterns in the cheese cooperative are more stable because, despite smaller flock size, milk supply is stable and sufficient to fulfill the cooperative's demand for raw milk from early 2020 to early 2023 (2017 shock).

In the cooperative's cash balance (Figure 3.26), seasonal oscillations are not as prevalent during an approximate two-year interval after recovery from below average rainfall. However, following the carrying capacity overshoot, larger seasonal profitability oscillations temporarily become prominent for producers and for the cooperative.

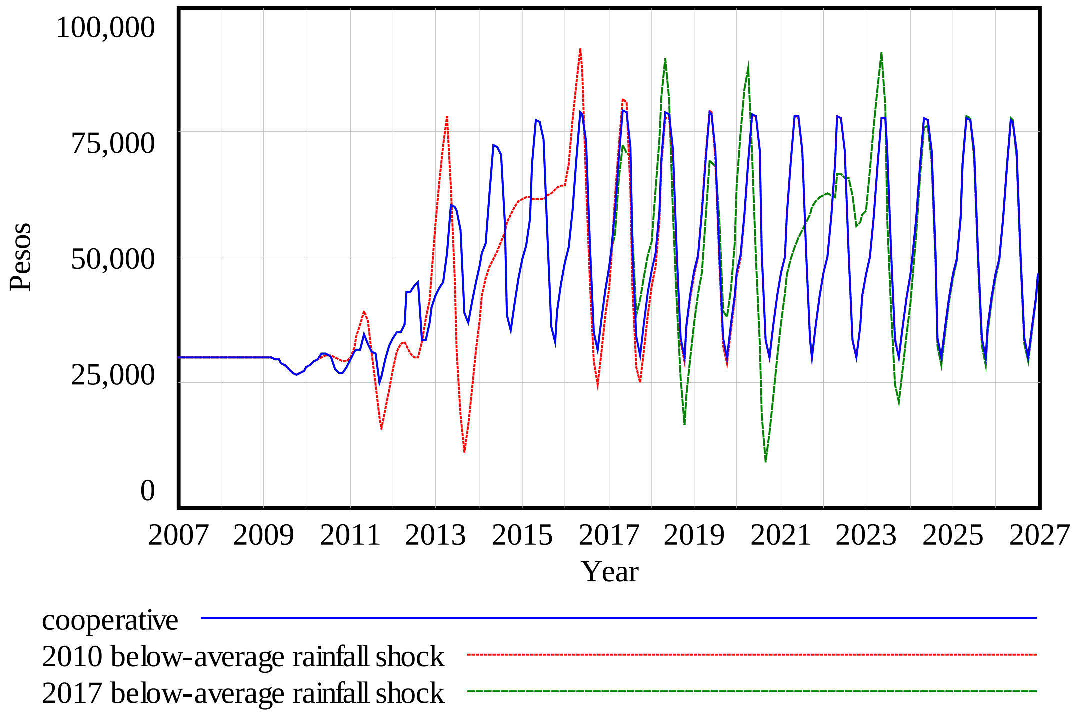

Figure 3.26 Cooperative cash holdings with 2010 and 2017 below-average precipitation shocks.

Cheese cooperative cash holdings do not suffer substantially due to the low precipitation shock. Figure 3.26 illustrates the stabilization (i.e., seasonal oscillations are not evident) of cash holdings during a two-year period when milk supply is unconstrained by seasonality of forage production. However, additional uncertainty in cash holdings due to changes in balance patterns over time could be problematic for management decision making.

Only slight losses in cumulative profits for farmers are incurred. Losses are not greater due to several factors including a decrease in forage production costs during the drought period. This occurs because less forage production requires less labor-related costs for maintenance. The cumulative profitability of fluid milk, dividend receipts, culled animals, and *cabritos* are relatively unchanged during and after drought recovery. Additional income from dividends maintains the profitability of goat operations well above the level of initial conditions. Consequently, after the low rainfall period, producers purchase goats and decrease culling while the mortality and kidding rates return to reference values by 2024, five years after the end of the below-average precipitation shock.

3.2.5.3 Combined Market and Low Precipitation Shocks

The two-year market shock beginning in January 2019 was combined with the three-year below-average rainfall shock beginning in January 2017 to assess the combined impact of the market and production shocks. The results are compared to the base cooperative simulation in Figure 3.27.

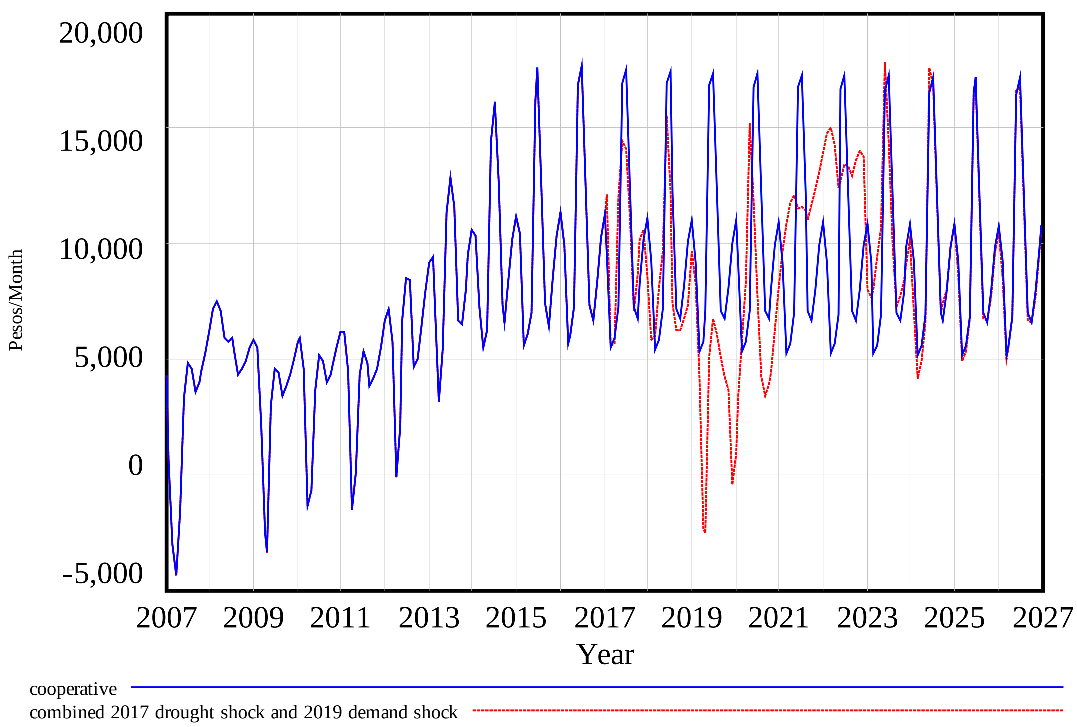

Figure 3.27 Monthly profitability of aggregate community caprine operations. The cooperative simulation (solid line) is contrasted with the results of the combined market and low rainfall shocks.

The combined shocks are expected to have a more adverse effect on the profitability of caprine activities than the individual shocks. The combined shocks resulted in a 66,000 peso decrease in cumulative profitability compared to the cooperative simulation. Thus, the shock does affect profits, but like the other tested shocks, the effect is not large ($66,000 pesos or 3% < cooperative simulation).

Following the shocks, the flock recovers in the absence of forage constraints. Therefore, resource stabilization eliminates limitations to production because the effects of seasonality in rainfall and forage production are temporarily removed. As indicated in Section 3.2.5.2, this assumes that the nonlinear effects associated with biological and management responses to forage and profit shortfalls react quickly enough to prevent more serious resource depletion during periods of market and production shocks.

3.2.6 Cooperative Sensitivity Tests

The objective of comprehensive parameter sensitivity testing is to evaluate the probability that operation of the cooperative is infeasible (i.e., cooperative would fail financially or producer incomes would drop below historical levels) given the uncertainty in specifying parameter values. Sensitivity tests were completed for all model parameters. Only parameter changes that produced numerical, behavioral or policy-sensitive[34] results are reported (Table 3.4). All sensitivity tests were conducted using a Latin Hypercube sampling approach with 100 simulations. Parameters were tested

[34] Parameters are defined as policy-sensitive only if the test indicates the possibility of community caprine profitability levels below the baseline simulation or a higher probability of cooperative bankruptcy.

individually using the default conditions of the cooperative simulation (Table A2.3).

Table 3.4 Parameter Sensitivity Test Responses

Parameter	Default	Range Tested	Sensitivity Result
Cheese yield	0.10 kg/kg	0.05 to 0.15	Numerical, behavioral, policy
Proportion adult does	0.6 dmnl	0.4 to 0.8	Numerical, behavioral, policy
Milk productivity per goat	1.5 kg/goat/day	0.5 to 3	Numerical, behavioral, policy
Unit costs to produce milk and traditional cheese	2 pesos/kg	0 to 4	Numerical, behavioral, policy (caprine profits)
Milk consumption per kid	1 kg/goat/day	0.5 to 2	Numerical, behavioral, policy (caprine profits)
Percentage above Xico milk price	0	-1 to 1	Numerical, behavioral, policy (cooperative)
Unit fertilizer costs	5 pesos/kg	5 to 10	Numerical
Average weaning time	3.5mo	2 to 5	Numerical
Base milk price	4 pesos/kg	3 to 5	Numerical
Base area in production per family	3 ha/household	1 to 3	Numerical
Base cheese production costs	10 pesos/kg	5 to 15	Numerical

base cheese storage costs Base cheese marketing costs	5 pesos/kg/mo 10 pesos/kg	2.5 to 7.5 5 to 15	
Initial aged cheese price	120 pesos/kg	100 to 140	Numerical
Minimum desired cooperative cash	30,000 pesos	0 to 60,000	Numerical,
Monthly cheese purchases per buyer	10 kg cheese / (buyer*month)	5 to 15	Numerical
Number of families	25 families	20 to 30	Numerical
Ref monthly forage productivity	250 kg/ha/mo	200 to 300	Numerical (production)
Total buyer population in Xico	30 buyers	10 to 50	Numerical

The six policy-sensitive parameters are constants related to flock makeup, cheese yield, milk productivity, production costs, milk consumption, and fluid milk price. The raw milk price, evaluated in Section 3.2.4.1, and the cheese yield are the only cooperative management policy-sensitive variables[35]. Among the policy-sensitive variables, the uncertainty in cheese yield, proportion of adult does[36], and milk productivity could cause community

[35] Cooperative management variables are those that are set by the cooperative (i.e., cooperative sets the milk price and selects cheese variety).
[36] Does are divided into a stock of weaned *cabritas* and a stock of adult does. Thus, a value of 0.6 in this variable indicates that 60% of does are adult does and 40% are weaned *cabritas*. The exact flock makeup is unknown.

caprine profits at or below historical levels and cooperative failure. In addition, unit costs to produce milk and traditional cheese and milk consumption per kid could produce community caprine profits at or below historical levels. Finally, the variation in the percentage above Xico milk price is capable of inducing cooperative failure. Combined with the results of production and market shocks (Section 3.2.5), the limited number of policy-sensitive parameters suggests that the basic idea of the cooperative may be financially feasible and likely to increase profits from Micoxtla caprine activities.

Cooperative Management Sensitivity

In this model, cooperative management structure is organized in a generic and adaptable manner. The assumptions (Appendix 2, Table A2.2) may be adequate for broad policy implications, which was the intention of this policy analysis, but should be further specified for a more case-specific *ex ante* impact assessment. For example, assumptions were made about how cooperative managers might actually make decisions. These assumptions (Section 2.3.3.2.7 and Appendix 2, Table A2.3, Part D), and possibly other more complex cooperative management policies, would change for each individual cooperative depending on its management objectives. Thus, future model testing should include sensitivity tests of the management policy, which will provide further indication of the most effective policies under alternative production and market conditions. A sensitivity test was conducted to simultaneously evaluate variations in minimum desired cooperative cash holdings ($10,000 to $50,000 pesos) and cost coverage time (1 to 5 months). Results were only numerically sensitive.

Cooperative Costs Sensitivity

The simulation model was organized so that the cooperative pays capacity expansion and capacity maintenance costs, production costs (i.e., management salaries), cheese storage costs, and cheese marketing costs. The value of these costs, as well as the price of the generic aged cheese that is processed and marketed by the cooperative, were unknown. Other possible costs and fees such as legal cooperative incorporation fees and initial cooperative infrastructure investment fees were excluded from the boundary of this model. The aged cheese price and costs sensitivity test (Figure 3.28) provides insight about the importance of this uncertainty.

The hypothetical price of aged cheese and its associated costs are chosen based on estimates for the Xico region, and the cooperative is profitable given these estimates. Nonetheless, under the default assumptions of the cooperative simulation, aged cheese production is unprofitable on a seasonal basis (Figure 3.9) when inventory is exhausted after milk supply becomes limiting. In the sensitivity test, the unit costs and price of aged cheese are varied by 25% above and below default values (Appendix 2, Table A2.3) to test the sensitivity of costs and price on community caprine profits (Figure 3.28).

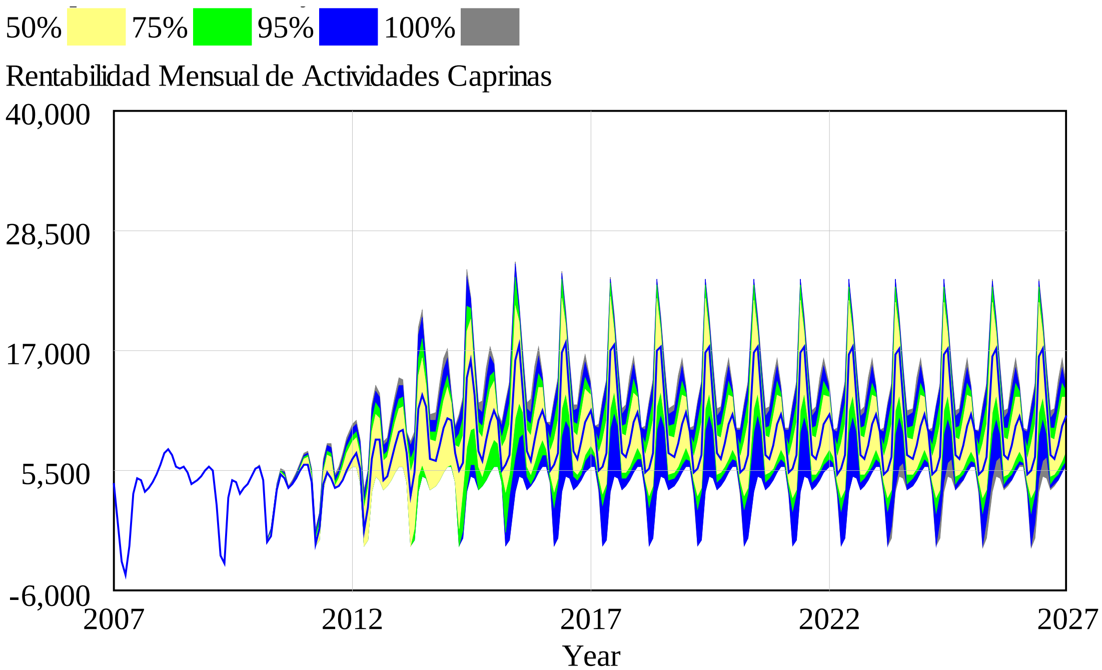

Figure 3.28 Sensitivity test: Confidence bounds for monthly profitability (pesos/month) of community caprine activities given 25% upper and lower variations in unit production, storage, and marketing costs, and in the price of aged cheese. The lowest extreme of the confidence interval is equivalent to the base simulation.

The sensitivity test (Figure 3.28) also demonstrates differences of over $ 1,900,000 pesos in cumulative profits for community goat farmers. The combination of lower prices and higher costs does not permit dividend payments. In these simulations, the lower extreme of the confidence interval for cumulative community caprine profits is equal to base simulation values. It does not drop below baseline levels because the cooperative pays producers the local market price for fluid milk. This indicates the importance of understanding market demand and assessing cooperative costs associated with the production of aged cheese. If these costs are greater than the market price for aged cheese, the processing and marketing cooperative would be an infeasible business venture incapable of improving the profitability of community caprine activities.

3.2.7 Final Discussion

A favorable cooperative management policy to increase the profitability of producer caprine activities is to pay producers the market price for raw milk and to distribute dividend payments (cooperative simulation). The exact combination of raw milk payments and dividend payments depends on numerous variable market and production parameters that evolve over time. Thus, it is unrealistic to suggest an ideal cooperative management structure based on these results. Rather, the cooperative can learn from potential results about alternative management policies to improve their decision-making and prevent potentially detrimental errors. Success of the cooperative was assessed through solvency, dividend payments, and the ultimate profitability of community caprine activities. Furthermore, policy sensitivity may depend on more than just profits. For example, if the cooperative does not pay farmers for raw milk, it achieves solvency more quickly and makes higher dividend payments to producers during a more favorable time of year (i.e., when other sources of agricultural income are limited). Thus, policy sensitivity depends on ultimate producer and cooperative objectives, producer buy-in, farmer needs, and dividend payment timing. Ultimately, the numerical differences in cumulative profitability are not substantially different (Table 3.3). It may be more important to further evaluate other policy indicators than just profit alone.

The tested shocks (market and low precipitation) do not create new profit trajectories or multiple equilibrium levels. Following the shock recovery period, as long as other model assumptions have not changed, numerical and behavioral patterns return to previous levels of oscillatory equilibrium. Under current model assumptions, the seasonal effects of exogenously imposed rainfall patterns are stronger than other endogenous effects in the model. Thus, under adverse shock conditions, profitability and production levels usually return to pre-shock oscillating levels after the shock recovery period. This also occurs as a result of the nonlinear biological effects and producer decisions in the model, which respond quickly enough to prevent resource depletion. The response of flock and cooperative management strategies indicates successful participatory education and training by INIFAP and the community. Exceptions to successful shock recovery are extreme shocks that induce liquidation of the flock. These extreme conditions shocks (e.g., multi-year extreme drought) were not fully evaluated.

The least favorable option for goat producers is to continue the historical pattern of milk production and sales. Under this strategy, the profitability of goat farming is likely to remain uniformly low and variable over time (Figure 3.3). The advantages of producer participation in the cooperative depend on a number of factors with high uncertainty in real life and in the model. These parameters were evaluated in univariate sensitivity tests (Table 3.4). Furthermore, a multivariate test was analyzed for cooperative costs (Figure 3.28).

Simulation model results indicated that if a market exists, or could be developed, for high value aged cheese, the activity could increase the profitability of producer caprine operations. It may also increase the capacity of goat farmers' to buffer their income in times of adversity (e.g., production or market shocks) by providing an additional source of agricultural income from cooperative dividend payments. This is especially important during the dry season when other forms of agricultural income are low. Model results suggest that due to delays in cheese processing and sales, most dividend payments would be made during the dry season. Furthermore, as suggested by Staal et al. (1997), a value-added dairy cooperative may reduce transactions costs for participating farmers. Although the current model does not differentiate between transactions costs for fluid milk sales in Xico and fluid milk sales to the cooperative, it could be another important motivating factor for producer participation in the cooperative. Finally, farmers hold more collective bargaining power as a collective unit in the market than they presently do as individual salesmen of fluid milk. This is another advantage of cooperative participation.

The cooperative could also add other services to assist goat producers in improving the quality and quantity of milk supply. For example, the cooperative could provide veterinary services, vaccinations, management information, sanitary milking information and training, and additional inputs to improve milk supply. It could act as a forage clearinghouse to provide affordable feed alternatives during the dry season. Cooperative cheese quality and goat farmer satisfaction could improve as a result. However, these services would come at a cost. The cooperative might be forced to pay a lower price for raw milk or to temper its dividend payment policy in order to provide these services. Alternatively, the higher quality milk could permit the cooperative to charge a higher price for its products, thereby compensating the additional costs of providing these services to goat farmers in Micoxtla.

An initial investment[37] in the cooperative is necessary to commence operations. This initial investment would likely need to come from development funds. In addition, cooperative managers would need to receive training in hygienic cheese processing, facilities repair and maintenance, and business management practices (e.g., accounting, customer relations, and marketing). The training program could be organized and delivered by INIFAP or another development organization. Additional risks to cooperative success include corruption, lack of farmer participation (supply limitations), market limitations, and product quality issues.

The model permits testing multiple scenarios and combinations of simulations. It will be delivered to the INIFAP team for future evaluation, model testing, and policy analysis exploration. This should help contribute to improved *ex ante* insight about the feasibility of this and other ideas for value addition and cooperative management in Micoxtla.

[37] This investment is arbitrarily placed at $30,000 pesos, the initial cash holdings of the cooperative, and a small exogenous productive capacity investment. The investment does not include infrastructure costs.

CHAPTER 4

CONCLUSIONS

This chapter is divided into two sections. First discussed are the lessons learned from the introductory system dynamics short course. Specific lessons include elements of interdisciplinary research, *ex ante* impact assessment, group model building, and multi-institutional advantages from systems thinking and modeling. The second section provides the overall conclusions and recommendations based on the value-added cooperative model. The conclusions in the second section are intended primarily as points for reflection by the INIFAP team in Xalapa, Veracruz. These also serve to facilitate further multi-institutional dialogue on system dynamics and *ex ante* analysis of complex agricultural research and development problems.

4.1 System Dynamics Short Course for INIFAP

The system dynamics short course was deemed successful by both the author and course participants[38], especially considering the numerous challenges and limitations in the traditional INIFAP workplace that were outlined in Section 3.1. For example, INIFAP employees are confronted by a demanding work load where available time is a severe constraint. In this environment, investments in a continuing education curriculum like the system dynamics short course are fruitful but with fewer returns than with less severe time constraints. Nonetheless, by investing in continuing education INIFAP not only promotes individual professional development, but also increases its own

[38] Overall, course participants indicated in self-administered evaluations that the course successfully met their objectives.

institutional capacity. Evidence for the perceived value of the system dynamics course for INIFAP was exhibited by the excellent attendance in the final workshop.

During the short course, team and group model building exercises were completed. The participatory nature of these exercises allowed participants to learn introductory system dynamics techniques while applying their knowledge to real world problems in a structured way. The most engaged discussions during the course occurred during team model building presentations. This was interpreted as evidence of learning and interest in system dynamics and in the selected problems.

Several overarching insights and lessons about teaching system dynamics in an institution emerged during organization and delivery of course mechanisms. One such insight is that additional emphasis on the qualitative problem conceptualization phase of the modeling process would prove beneficial to enhance the development of feedback thinking and dynamic intuition. In contrast, lectures and exercises in the development of quantitative simulation models during this first course challenged most participants more than it improved comprehension of essential concepts. This suggests that the quantitative phases of modeling could be better placed in a second short course for advanced students.

The insights gained from teaching the short course and reflections offered in this document could prove useful for future attempts to build institutional capacity in undertaking *ex ante* impact assessments with system dynamics or similar methods. In general, course participants seemed to comprehend the strengths and weaknesses of system dynamics for *ex ante* analysis of complex problems, and are capable of applying this modeling process at least through problem conceptualization (problem articulation and dynamic hypothesis building). However, human capacity is generally insufficient to correctly deduce the behavioral dynamics in a complex conceptual model, and simulation is one of the few alternatives for testing a dynamic hypothesis (Sterman, 2000). Thus, there is a need for formal simulation to reveal the implications of a dynamic hypothesis to ultimately improve problem understanding and decision-making.

4.1.1 Interdisciplinary Advantages

System dynamics is inherently interdisciplinary (Sterman, 2000), which could make the interdisciplinary makeup of the INIFAP team a great advantage for the analysis of interdisciplinary problems. The team consists of agronomists, computer systems specialists, horticulturists, environmental scientists, animal scientists, agronomists, participatory research and rural development specialists, and statisticians. However, several course participants recognized this team composition to be an underexploited potential by saying that members primarily focus on their respective disciplines but infrequently interact, share ideas, or collaborate. System dynamics offers an accessible framework from which interdisciplinary research collaboration could be more readily fomented among members of the INIFAP team. An effective method for applying system dynamics to interdisciplinary problem solving is group, or team, model building such as the entry-level educational case studies undertaken by small groups during the short course (Vennix, 1996).

4.1.2 Group Model Building

The INIFAP team has the potential to pioneer group model building interventions for agricultural research and development in Mexico. The participatory modeling methods applied by INIFAP created a practical educational environment, where the course participants were also the modelers. The success achieved using this form of group model building was uncommon, especially in a Mexican governmental institution dedicated to agricultural research. This success could be replicable, or even advanced, for individual and institutional capacity-building when the participants have sufficient computer, analytical, and quantitative training to understand, interpret, and appropriately apply system dynamics methods beyond conceptual analysis. It could be especially advantageous in agricultural development applications.

Participatory model-building can facilitate *ex ante* impact assessments. However, an institutional commitment is required to invest the necessary time and financial resources in the development of modeling interventions to take better advantage of this methodology. It may be necessary, if not essential, to provide incentives to INIFAP workers to learn and to apply system dynamics as part of the existing research and development toolbox.

Finally, group model building using system dynamics methods provides a platform to facilitate multi-institutional collaboration to resolve complex agricultural development problems. This was exemplified during the short course and the January 2008 IARD 602 field laboratory. Students from Cornell University, the University of Veracruz, and INIFAP successfully collaborated on the problem articulation phase of the system dynamics modeling process. The effectiveness and impact of *ex ante* assessments and resulting interventions could benefit by involving multiple institutions, community members, and other stakeholders in the modeling process.

4.1.3 *Ex ante* Impact Assessments Using System Dynamics

Two *ex ante* impact assessment cases were undertaken during the course: the feasibility of value-added cooperatives and diversification of the coffee plantation (López Ramírez, 2008). These constituted complex problems of high interest to INIFAP, and will be useful to INIFAP for educational purposes and for policy analysis. Both studies comprised dynamic simulation models. In both cases, model results suggest that the diversification of small farms with alternative forms of agricultural income generation is vital to sustain livelihoods. Diversification can mitigate risks given seasonal and yearly uncertainty in weather, soil fertility, and commodity prices, given current limited resources. These cases contribute to the limited number of system dynamics applications in agriculture and rural development.

4.1.4 Benefits of System Dynamics for INIFAP

Future *ex ante* impact assessments could be improved by applying system dynamics with other analytical techniques (e.g., statistical analysis and GIS). For example, INIFAP has the opportunity and budding expertise to incorporate feedback thinking into *ex ante* assessment and data analysis. In contrast to other techniques used by INIFAP (Section 3.1.1.7 and 3.1.1.8), system dynamics emphasizes behavioral changes over time, and short and long-term results. For example, as a leader in GIS research, INIFAP-Xalapa is analyzing changes in crop production potentials over time. Currently, static models based on climate-change predictions are used to spatially map these potentials. Important dynamic factors such as producer decisions, government policy, and shifting market demand over time are excluded. System dynamics would allow INIFAP to broaden the scope of crop production and productivity studies, which could be a useful decision support mechanism for INIFAP and other agricultural policy decision makers.

Furthermore, if INIFAP computer specialists can achieve their goal of linking GIS models with dynamic models, either directly or indirectly, they could become a leader in the creation of spatial models that change over time based on endogenous feedback structure. Ultimately, long-term decision making could be improved for governments, producers, and other stakeholders.

4.2 Value-Added Cooperative Model

The value-added cooperative model was prepared together with course participants as an *ex ante* impact assessment mechanism and an adaptable case study. The dynamic biophysical and socioeconomic model facilitated the assessment of information needs, opportunities, and limitations to value-added agricultural production in the region. It also permitted analysis of value addition and marketing cooperatives for smallholders.

4.2.1 Value Addition to Agricultural Products

The value-added cooperative model facilitates the examination of the importance to outcomes of various assumptions. This facility will be useful for future policy analysis by INIFAP. The model provides insight about the opportunities, limitations, and information needs for value-added dairy products and other higher value products with potential for commercialization such as blue maize derivatives, higher value vegetables, and other traditional products. Similar to aged cheese, these products have potential for success in a “niche” market. Because the primary goal is to help community goat farmers sustain their livelihoods by increasing farm profits, this should also be the overarching goal of any development intervention in Micoxtla and surrounding communities.

4.2.2 Value Addition and Marketing Cooperatives

Cooperative management strategy is vital to determining whether the cooperative will succeed in improving the profitability of community caprine operations. The analysis suggests that paying the current market price for fluid milk to goat farmers and distributing profit-sharing dividends is a viable option to increase goat producer net profits. Other options exist, but the difference in cumulative profitability of aggregate community caprine activities is minimal.

A number of analyses suggest that exogenous shocks to the system (e.g., market and production shocks) temporarily worsen monthly net incomes for farmers, but may not have a substantial negative impact on farmer profits due to effective biological and decision-making responses. In contrast, although cooperative management strategies are resilient, the cooperative may be incapable of withstanding bankruptcy after severe production or market shocks due to losses during the shock period. Access to credit is important to sustain cooperative operations during these times. Under environmental and market conditions when high-value cheese production is profitable, the activities of the cooperative increase farmer profits to a higher, but oscillating, level compared to previously-observed levels. This and the expected decrease in transactions costs for milk marketing and transportation (which was not analyzed) indicate that a value addition and a marketing cooperative could be a favorable option for goat farmers.

4.2.3 Information Needs and Next Steps

Numerous factors contributed to uncertainty of the simulation outcomes, as assessed through sensitivity analyses (Section 3.2.6). Highly uncertain parameters affect whether the value-added production and the marketing cooperative will generate increased farmer profits (Table 3.4). These parameters should be given priority for future data collection and analysis by INIFAP. Several numerically sensitive parameters are critical to the success of the cooperative: the market for value-added products (i.e., market size and product price), the management strategy of the marketing cooperative (i.e., dividend disbursement strategy and price paid for fluid milk), and consumer preferences for value-added products.

Another possible threat to cooperative success is the development of additional businesses that would compete with the cooperative for market share of value-added products. Extensions of the current model could permit analysis of resulting shifts in market demand and market price for value-added products to more fully analyze the effect of increased competition. Additional risks to cooperative success include: milk supply limitations, market insufficiency, product quality problems, unavailable credit, and corruption.

Due to the importance of market characteristics and potential, INIFAP and community members should also complete an extensive market assessment for any value-added products prior to encouraging productivity increases or beginning community-based income generation projects. The risks of policy resistance and unintended consequences increase if market size and market dynamics are not evaluated prior to producing and attempting the commercialization of these products. If there is no market for aged cheese, the market is too volatile, or costs are underestimated, there will be little or no advantage to cooperative aged cheese initiatives. In some cases, the cooperative would fail and goat farmer incomes would remain at their previous observed levels.

Finally, the forage component of the model is highly simplified and may need to be further disaggregated depending on the objectives of the model users. In its current form, the forage component provides a rough estimate of forage production quantities and acts in the determination of an important carrying capacity attribute in the system (the fractional forage needs satisfied). While rainfall seasonally limits forage production, nutrient availability is likely to define the capacity limit for forage supply and forage quality when rainfall is not limiting. Further research and model structure assessment tests incorporating a forage nutrient co-flow structure could be used to evaluate the importance of nutrient availability to animal performance.

4.3 Personal Reflections

As stated in the preface, the author's personal goal for this applied thesis project was to provide capacity building assistance to an international organization or community. This goal was attained despite modest acceptance by the INIFAP Xalapa team given the short-term nature of the intervention and institutional constraints. The author also achieved personal learning objectives by gaining further educational and career focus, and applied experience in the use and teaching of system dynamics modeling for *ex ante* analysis of agricultural development problems. In addition, as a partial result of the interdisciplinary modeling work led by the author (Section 3.2), the exclusion of forage quality from the analysis was identified as a major limitation in this caprine production analysis. This realization, combined with previous forage management interests in mixed crop-livestock systems in Nebraska and Nicaragua have led to a shift in career objectives to forage nutrient management for mixed crop-livestock systems. The author is thus embarking on doctoral studies in this area.

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APPENDIX 1:

INTRODUCTORY SYSTEM DYNAMICS COURSE OUTLINE, FINAL WORKSHOP OUTLINE, AND LITERATURE LIST

Título: Introducción al Pensamiento Sistémico y Modelación Dinámica de Problemas

Audiencia Principal: Equipo del INIFAP Campo Experimental en Teocelo

Ubicación: Xalapa, Veracruz, México

Objetivos Principales:

1. Aumentar el conocimiento de los participantes en técnicas básicas de análisis de productos agropecuarios con valor agregado a través de modelaje con dinámica de sistemas.
2. Analizar y evaluar aspectos de una estrategia potencial para aumentar la rentabilidad de actividades agropecuarias: el caso de queso fino de cabra.
    a. Aclarar parámetros, suposiciones, estructura, ciclos de retroalimentación, modos de referencia, etc.
3. Modelar otros problemas o productos con dinámica de sistemas.
4. Generar confianza en el modelo de queso fino con el fin que sea una herramienta útil y adaptable para evaluar el potencial de producción de queso fino para el equipo de INIFAP.

Programación:

I. Semana 1 (18-22 de junio)

- Orientación: Presentar objetivos y estructura del las sesiones (Sesión 1)

    - Planificación de las sesiones y el calendario
    - Explorar expectativas de los participantes
    - Aclarar dudas sobre la dinámica de sistemas y la utilidad de modelaje con dinámica de sistemas
- Introducción I a la dinámica de sistemas (Sesión 2)

II. Semana 2 (25-29 de junio)

- Introducción II a la dinámica de sistemas (Sesión 3)
    - Formar grupos de trabajo
    - El Proceso de modelaje por dinámica de sistemas
- Introducción y instalación del Vensim PLE
    - Ejercicio introductorio con Vensim PLE
- Modos fundamentales de comportamiento I (Sesión 4)

III. Semana 3 (2-6 de julio)

- Modos fundamentales de comportamiento II (Sesión 5)
    - Ejercicio: Identificar y evaluar modos fundamentales de comportamiento con el ejemplo de queso fino de cabra
- Introducción al problema de queso fino de cabra – discutir escenario y historia del problema (Sesión 6)
    - Ejercicio: Dibujar modos de referencia imaginados por los participantes
    - Ejemplos de los pasos del proceso de modelaje
    - Revisar literatura de apoyo y discusión
- Segundo ejercicio con Vensim PLE

IV. Semana 4 (9-13 de julio)

- Diagramas de ciclos causales (Sesión 7)

   - Ejercicio: Identificar y dibujar ciclos causales importantes con el ejemplo de queso fino de cabra

V. Taller Internacional de Microcuencas (17 de julio)

- Presentación de "Alternativas económicas en microcuencas de montaña: Potencial del queso añejo de cabra."

VI. Semana 5 (23-27 de julio)

- Resumen de material cubierto, preguntas y discusión (Sesión 8)
- Reservas y flujos (Sesión 9)
   - Cuarto ejercicio con Vensim PLE sobre diagramas de reserves y flujos
   - Identificar las reservas y flujos en el ejemplo de queso fino de cabra
- Dinámica de reservas, flujos y estructuras sencillas (Sesión 10)
   - Ejercicio Vensim sobre reserves, flujos y estructuras sencillas
   - Estructuras sencillas en el ejemplo de queso fino de cabra
- Presentaciones grupales: definición del problema (Presentación 1)

VII. Semana 6 (30 de julio - 3 de agosto)

- Resumen y discusión de la semana anterior
- Retrasos de material (Sesión 11)
   - Ejercicio en Vensim sobre retrasos
- Retrasos de información (Sesión 12)
- Dinámica de estructuras sencillas (Sesión 13)

VIII. Semana 7 (6-10 de agosto)

- Modelo conceptual de queso fino (Sesión 14)
   - Ejercicio: Evaluar modelo conceptual de queso fino

- Presentaciones grupales: La hipótesis dinámica, un modelo conceptual (Presentación 2)

IX. Semana 8 (13-17 de agosto)

- Consultas individuales
- Reglas de la toma de decisiones I (Sesión 15)
- Resumen y discusión del ejercicio de dinámica de nutrientes en la región amazónica
- Reglas de la toma de decisiones II (Sesión 16)
- Relaciones no-lineales y la formulación de ecuaciones de flujo (Sesión 17)

IX. Semana 9 (3-7 de septiembre)

- Consultas individuales

X. Semana 10 (10-14 de septiembre)

- Cadenas y co-flujos (Sesión 17)
- Integración numérica (Sesión 18)
    - o Ejercicios prácticos de integración numérica

XI. Semana 11 (17-21 de septiembre)

- Modelación de expectativas (Sesión 19)
- Evaluación de modelos I y II (Sesión 20)

XII. Semana 12 (24-28 de septiembre)

- Taller Final (vean detalles en las siguientes páginas)

Taller Final del Curso-Taller,

“Introducción al Pensamiento Sistémico y

Modelación Dinámica de Problemas”

27 a 28 de Septiembre de 2007

Jueves 27 de septiembre:

9:00am – 12:00pm - Resumen final del curso, repaso de los temas fuertes

11:30am – 12:30am – Revisión de objetivos del curso

11:10am – 11:30am – Descanso

11:30am – 12:10pm – Demonstraciones prácticas:

- El uso de datos en un modelo
- Equilibrio dinámico - importancia y utilidad de iniciar un modelo en ED

12:10pm – 2:10pm – Actividad práctica, experimentación con modelo de queso fino

- Entregar reacciones escritas

2:10pm – 2:30pm – Descanso

1:30pm – 3:30pm – Actividad práctica, experimentación con modelo de queso

- Entregar reacciones escritas el viernes

Viernes 28 de septiembre:

9:00am - Discusión del problema y modelo de queso fino, los supuestos, lecciones aprendidas, dudas, problemas, resultados de evaluación y análisis de políticas

- Lecciones aprendidas y sugerencias del modelo

10:00am – 12:00pm – Presentaciones finales del modelaje de un problema por grupo (Presentación 3)

a) 9:00am- 9:40am – Desnutrición – Modesto, Giovana y Armando
b) 9:40am – 10:20am – Sobrepeso – Columba y Fernando
c) 10:20am – 11:00am – Cafetal Diversificado – Rafael, Martin y Rosalio

12:00pm – 12:30pm - Comentarios finales sobre el proceso de modelaje, el progreso de los grupo y los próximos pasos

12:30pm – 12:40pm – Descanso

12:40pm – 1:40pm – Planificación del futuro trabajo del equipo de INIFAP que podría utilizar la dinámica de sistemas

- ¿Qué otros problemas les interesa modelar?
- ¿Qué son los pasos del proceso?
- Discusión y conclusiones

1:40pm – 2:00pm – Revisión de los objetivos del curso/taller, agradecimientos

- Comentarios y observaciones finales
- Futuro evaluación del curso
- Tesis de estudio *ex ante* de queso fino
- Futuro seguimiento y clausura del curso

2:00pm – Entrega de constancias

Literature Cited During System Dynamics Short Course

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APPENDIX 2

VALUE-ADDED COOPERATIVE MODEL DOCUMENTATION: BOUNDARY TABLE, ASSUMPTIONS, PARAMETER DESCRIPTION, LOOKUP FUNCTIONS, CHANGES IN KEY ASSUMPTIONS FOR SIMULATIONS, AND SEASONAL RAINFALL DATA

A model boundary diagram (Table A2.1) is used to define the frontiers of the model and is closely associated with model assumptions. Model components have been separated into endogenous, exogenous, and excluded model components. Endogenous components are included in the internal feedback structure of the model. Exogenous variables (model constants) lie outside the model boundary, but can affect feedback loop dominance and model performance. Excluded factors have not been included in the model structure.

Table A2.1 Model Boundary Table

Endogenous	**Exogenous**	**Excluded**
Goat Flock Stocks	Goat Weaning Delay	Milk Demand
Birth and Death Rates	*Cabrita* Fractional Death Rate	Forage Quality
Adult Does Purchases	Feed Purchases	*Cabrito* Demand
Culling Rate	Non-Feed Costs Per Doe	Labor
Goat Flock Decisions	Number of Families	Nutrient Cycles
Forage Resources	Milk Price	Adult Bucks
Forage Production Costs	Milk Costs	
Forage Production Decisions	Goat Kid Unit Milk Consumption	
Milk Production	Initial Investment in Aged Cheese Production Capacity	
Household Milk Consumption	Aged Cheese Yield	
Aged Cheese Production	Cheese Maturation Delay	

Endogenous	Exogenous	Excluded
Capacity		
Dividend Payments	Unit Specialized Cheese Production, Storage, and Marketing Costs	
Cheese Production Decisions	Adjustment Times	
Aged Cheese Production Stocks	Aged Cheese Sales Delay	
Profitability of Enterprises	Initial Stock Values (many are functions of constants to initialize model in dynamic equilibrium)	
Cabrito Price	Potential Aged Cheese Buyers	
Aged Cheese Price		
Aged Cheese Demand		
Forage Production Area Per Family		
Capacity Utilization		

An important model assumption is that forage supply is more important than forage quality. Therefore, forage quality and nutrient cycles have been omitted from the model structure. Additional model assumptions are laid forth by model component in Table A2.2.

Table A2.2 Model Assumptions (by model component)

I. Goat Flock
1. All animals in the stock of adult does produce milk.
2. Micoxtla goat farmers make decisions about goat flock composition (adult doe purchases and adult doe culling rate) based on the profitability of aggregate community caprine activities.
3. Culled goats can be sold at a fixed price.
4. All animals in the stock of adult does incur monthly non-feed costs (veterinary fees, vaccinations, working medication, facility maintenance, etc.)
5. All *cabritos* are either sold or used for household consumption, and all *cabritos* that are not consumed can be sold.
6. All goat kids in the stocks of *Cabrito* and *Cabrita* consume milk.

7. Breeding fees are not included in model accounting. These fees are assumed for the purpose of the analysis.
8. The fulfillment of required forage needs directly affects the fractional birth rate and the fractional adult doe death rate. This is based solely on quantity, not quality of available feed.
II. Forage Resources
1. Forage quality is excluded from the analysis. Thus, forage quantity is a more important limiting factor than forage quality.
2. If farmers perceive inadequate forage resources, they will attempt to increase forage production through productivity increases and land area expansion.
3. The forage availability attribute (fractional forage needs satisfied) nonlinearly affects the adult doe fractional death rate, the kidding rate, and milk production.
4. Seasonal rainfall patterns directly and proportionately affect forage productivity. In this case the effect is exogenous.
5. All feed is modeled as forage in the value-added cooperative model. Disaggregation may be necessary.
6. Hired labor is always readily available at a low cost. The cost is included in forage production costs.
7. Household labor for goat and forage production is always available free charge.
III. Milk Allocations
1. Producers do not limit *cabrito* milk consumption; therefore, a constant daily amount is assumed (Alvarez Montes de Oca, personal communication, August 16, 2007).
2. Goat producers will automatically sell fluid milk to the cooperative.
3. Goat producers will first fill the demand of the cheese cooperative for fluid milk before selling excess milk in Xico.
IV. Aged Cheese Production
1. Cancelled orders for aged cheese do not affect market demand.
2. Unit cheese production, storage, and marketing costs decease slightly in an exponential decay pattern as the cooperative obtains additional cheese making experience.
V. Aged Cheese Market
1. The number of actual buyers in Xico can be approximated using a variation of the Bass Diffusion Model (Bass, 1969, as cited in Sterman, 2000), which simulates an S-shaped growth pattern.
2. The price of aged cheese decreases as cheese production, marketing, and storage costs decrease (See IV, 2).

3. Not all potential buyers become actual buyers.
4. Commercialization launches the market demand structure.
5. Once buyers make their first purchase, they will continue to buy aged cheese.
VI. Cooperative Production Capacity
1. A small, initial, exogenous investment in capacity is free to the cooperative.
2. Capacity utilization can be varied by managers according to fluctuations in market demand.
3. Capacity expansion is made based on the expected market demand for aged cheese when sufficient cash is available.
4. Capacity slowly obsolesces over time.
VII. Cooperative Decisions and Cash Holdings
1. The cooperative's management policy is to maintain sufficient cash on hand to cover expected expenses for future months while avoiding times of economic crisis due to seasonal market uncertainties.
2. After covering costs, cooperative managers will always fulfill desired capacity investments prior to making dividend payments.
3. The primary goat of the cooperative is to maximize payments to goat farmers through fluid milk payments, dividend payments, or a combination of both.
4. Cooperative losses leading to negative cash holdings can be compensated in some way (grant, loan or gift) and do not affect cooperative operation.
5. Dividend payments can be made continuously.
VIII. Profitability Expectations
1. The profitability of goat enterprises is used by goat farmers make decisions about goat flock composition. Decisions are made based on 3rd order exponentially smoothed values for each enterprise with different adjustment times.

Table A2.3 Parameter Summary Table (by model component) for Base Simulation

Parameter Name	Default Value	Units	Source / Information
A. Control			
Time Step	0.0625	Month	
Initial Time	0	Month	
SavePer	1	Month	

Parameter Name	Default Value	Units	Source / Information
Initial Year	2009	Year	Timebase
Years Per Month	0.083333	Year/Month	Timebase
Final Time	240	Month	
B. Cooperative Productive Capacity			
Initial Cheese Cooperative Capacity	0	Kg Cheese/Month	
Unit Cost of Capacity	50	(Pesos*Month)/kg Cheese	
Capacity Utilization Switch	1	Dmnl	1=on, 0=off
Initial Exogenous Capacity Investment	20	Kg Cheese/(Mes*Mes)	
Expected Orders Adjustment Time	1	Month	
Initial Expected Order Rate	0	Kg Cheese/Month	
Capacity Acquisition Time	1	Month	
Average Capital Lifetime	240	Month	
C. Cooperative Aged Cheese Production			
Base Unit Storage Cost	5	Pesos/(kg cheese*Month)	
Base Unit Commercialization Cost	10	Pesos/kg Cheese	
Base Unit Production Cost	10	Pesos/kg Cheese	
Initial Experience	500	Kg Cheese	
Learning Curve	(0.02915)	Dmnl	Equivalent to a 5% cheesemaking cost decrease each time experience doubles (Sterman, 2000).
Endogenous Milk Price Switch	0	Dmnl	1=on, 0=off
Initial Orders	0	Kg Cheese	
Aged Cheese Price	0	Dmnl	

Parameter Name	Default Value	Units	Source / Information
Subsidy			
Percentage Above Xico Milk Price Paid by Cooperative	0	Dmnl	
Initial Proportion of Milk Destined for Aged Cheese Production	0	Dmnl	
Cheese Yield	0.1	Kg Cheese/kg Milk	
Minimum Delay in Aged Cheese Sales	0.25	Month	
Average Delay in Aged Cheese Maturation	4	Month	
Average Delay in Aged Cheese Sales	0.5	Month	
Perceived Cooperative Cash Balance Adjustment Time	1	Month	
Aged Cheese Price Subsidy Start Time	70	Month	
D. Cooperative Cash Flow and Decisions			
Minimum Desired Cash Balance	30,000	Pesos	
Dividend Switch	1	Dmnl	1=on, 0=off
Initial Cooperative Investment	0	Pesos/Month	
Initial Cumulative Profitability of Aged Cheese Enterprise	0	Pesos	
Capacity Investment Adjustment Time	1	Month	
Expected Dividends Adjustment Time	3	Month	
Expected Aged Cheese Profitability Adjustment Time	1	Month	
Dividend Start Time	0	Month	
Cost Coverage Time	2	Month	The desired amount of time to cover costs with

Parameter Name	Default Value	Units	Source / Information
			cash on hand.
Capacity Expenditure Delay	1	Month	
Dividend Expenditure Delay	4	Month	
Initial Cooperative Cash Balance	30,000	Pesos	
E. Forage			
Base Area in Production per Family	2	Ha/Household	INIFAP
Fixed Monthly Land Costs	10	Pesos/(Ha*Month)	
Unit Fertilizer Costs	5	Pesos/Kg	Cristóbal Carballo, 7-8 pesos for typical NPK mix
Reference Fertilizer Application	10	Kg/(Ha*Month)	
Required Forage Consumption per Goat	60	Kg/(Goat*Month)	INIFAP estimate
Seasonal Rainfall Switch	1	Dmnl	1=on, 0=off
Normal Monthly Rainfall Switch	1	Dmnl	1=on, 0=off This switch allows historical monthly rainfall data (INIFAP, 2006a) to proportionately affect forage productivity. It can be switched off to remove seasonality or to turn on seasonal data-based drought patterns.
Drought Switches	0	Dmnl	A series of data-driven drought patterns (INIFAP, 2006a) can be activated in lieu of

Parameter Name	Default Value	Units	Source / Information
			the normal monthly rainfall switch.
Monthly Labor Used Per Family	120	Hours/(Family*Month)	INIFAP – Approximately 4 hours caprine labor are invested / family / day.
Required Labor for Maintenance and Harvest of Unit Forage Produced	0.001	(Laborer*Month)/kg	This is the amount of labor required in months to harvest 1 kg of forage. 1 laborer can harvest 1000kg forage/month on average.
Months of Consumption	1	Month	Used to calculate value of initial forage resources stock
Monthly Payment for Hired Labor	50	Pesos/(Laborer*Month)	This monthly salary is quite low because most families do it themselves (INIFAP)
Number of Families	25	Households	INIFAP
Average Monthly Precipitation	174.537	Mm	INIFAP (2006a)
Average Monthly Forage Productivity	250	Kg/(Ha*Month)	INIFAP estimate, low productivity, value highly uncertain
Fertilizer Effect on Forage Productivity Adjustment Time	3	Month	
Production Area Adjustment Time	6	Month	
Smooth Fraction Forage Requirements Met Adjustment Time	2	Month	

Parameter Name	Default Value	Units	Source / Information
F. Goat Production			
Base Average Time in Flock	84	Month	INIFAP
Non-Feed Costs Per Goat	5	Pesos/(Goat*Month)	INIFAP
Litter Size	2	Dmnl	INIFAP
Average Age for *Cabrito* Sales and Consumption	1	Month	INIFAP
Fraction *Cabrita* Deaths	0.05	Dmnl	INIFAP
Kidding Interval	12	Month	INIFAP
Goat Purchase Adjustment Parameter	1	Month	
Percentage *Cabritas*	0.5	Dmnl	
Culled Goat Price	300	Pesos/Goat	INIFAP
Cabrito Price	300	Pesos/Goat	INIFAP
Proportion Initial Does that are Adults	0.60	Dmnl	
Proportion *Cabritos* Sold	0.90	Dmnl	INIFAP
Desired Adult Goats Adjustment Time	6	Month	
Minimum Residence time in Weaned *Cabritas* Stock	1	Month	
Minimum Residence Time in Flock	1	Month	
Average Weaning Time	3.5	Month	INIFAP
Average Delay in Doe Maturation from Weaning to Adults	21	Month	INIFAP
Purchased Goat Price	1,000	Pesos/Goat	INIFAP
G. Aged Cheese Market			
Start of Commercialization	0	Month	
Initial Actual Buyers	0	Buyers	

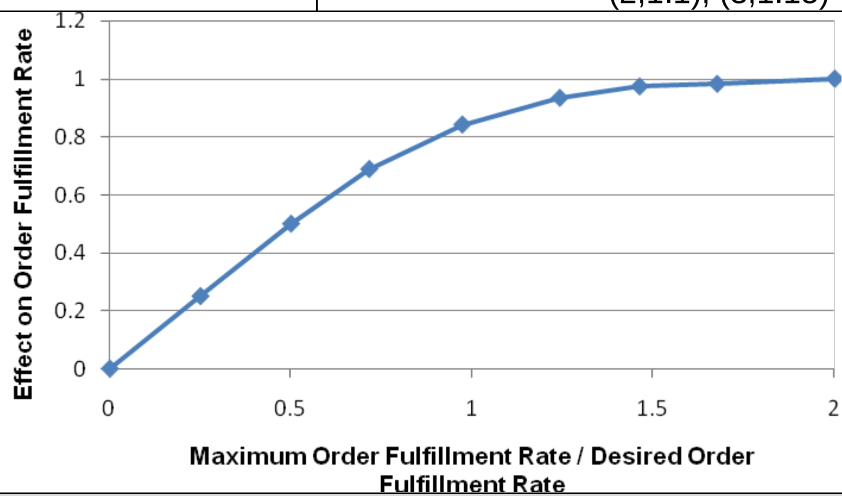
Parameter Name	Default Value	Units	Source / Information
Initial Purchases per Buyer	5	Kg Cheese/Buyer	
Average Consumption per Buyer	10	Kg Cheese/(Buyer*Month)	
Demand Shock	0	Kg Cheese/Month	
Demand Shock Duration	0	Month	
Demand Shock Time	0	Month	
Commercialization Effectiveness	0.005	1/Month	
Expansion to Other Markets	0	Buyers/Month	
Initial Population of Total Potential Buyers in Xico	30	Buyers	
Initial Aged Cheese Price	120	Pesos/kg Cheese	
Price Shock	0	Pesos/kg Cheese	
Price Shock Duration	0	Month	
Price Shock Time	0	Month	
Buyer Proportion that Adopts Aged Cheese	0.5	Dmnl	
Buyer Interaction Rate	0.25	1/Month	
Market Expansion Time	120	Month	
H. Milk Allocations			
Daily *Cabrito* Milk Consumption	1	Kg/(*Cabrito**Day)	INIFAP
Reference Household Milk Consumption	1	Kg/(Household*Day)	INIFAP
Average Days per Month	30.42	Days/Month	Conversion factor
Cooperative Switch	0	Dmnl	1=on, 0=off
Reference Daily Milk Production per Goat	1.5	Kg/(Goat*Day)	INIFAP, Nagel et al. (2006)

Parameter Name	Default Value	Units	Source / Information
Cooperative Start Time	24	Month	The cooperative begins marketing and processing operations in 2009.
I. Monthly Net Margins and Profitability Expectations			
Amplitude	0.5	Pesos/kg	INIFAP, amplitude of milk price oscillations in Xico market
Base Milk Price in Xico	4	Pesos/kg	INIFAP
Milk and Traditional Cheese Production Costs	2	Pesos/kg	INIFAP estimate
Seasonal Milk Price Switch	1	Dmnl	1=on, 0=off
High Milk Price Month	3.3	Month	Coincides with low milk productivity seasons.
Milk Price Shock	0	Pesos/kg	
Milk Price Shock Duration	12	Month	
Milk Price Shock Time	120	Month	
Cosine Parameter	2	Dmnl	
Period	12	Month	
Pi	3.14159	Dmnl	
Initial Cumulative Profitability of Goat Operations	0	Pesos	
Initial Cumulative Profitability of Goats and *Cabritos*	0	Pesos	
Initial Cumulative Profitability of Milk	0	Pesos	
Expected Forage Costs Adjustment Time	3	Month	
Smooth Monthly Profitability of Milk Adjustment Time	3	Month	

Parameter Name	Default Value	Units	Source / Information
Smooth Monthly Profitability of Goats and *Cabritos* Adjustment Time	10	Month	

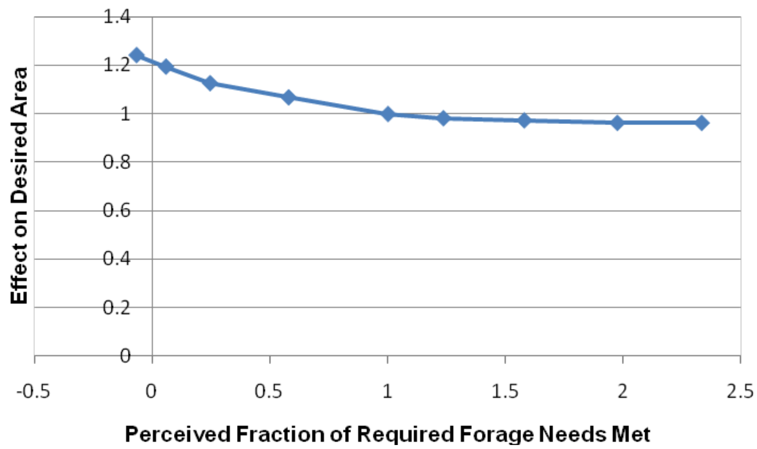
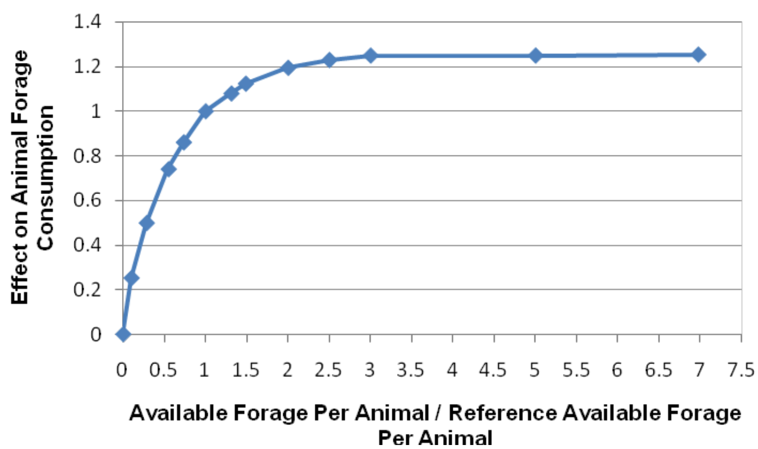
Table A2.4 Lookup or Table Functions[39]

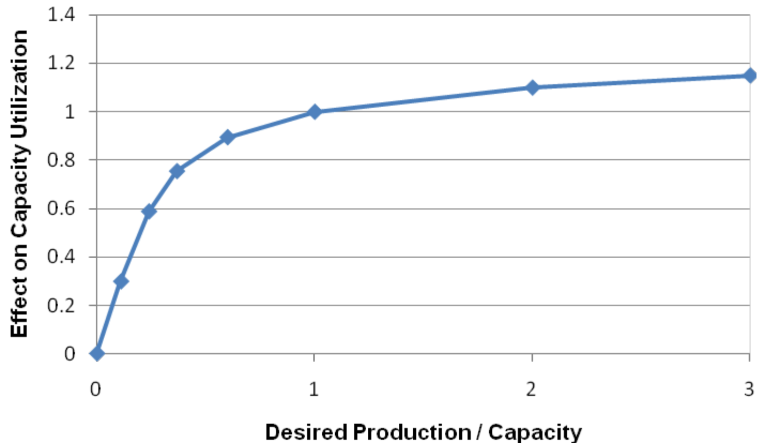
Name	Function Values[40]	Units
Order Fulfillment Table	(0,0), (0.110092,0.298246), (0.238532,0.587719), (0.366972,0.754386), (0.599388,0.894737), (1,1), (2,1.1), (3,1.15)	Dmnl



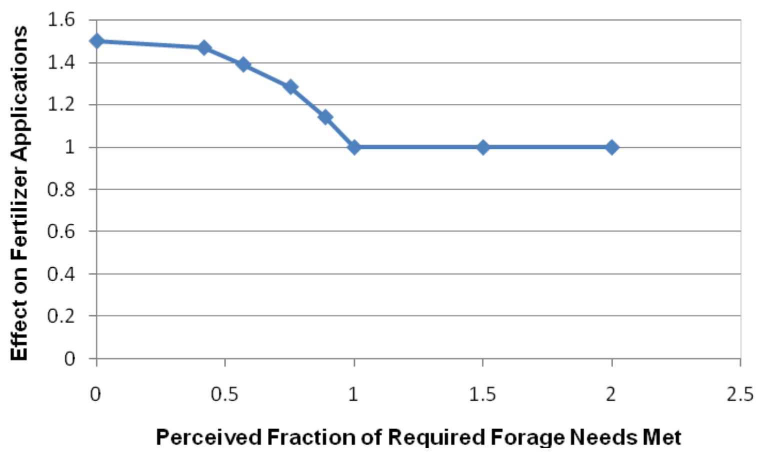
Effect of Perceived Required Forage Needs Met on Desired Terrain	(0,0), (0.25,0.25), (0.5,0.5), (0.715596,0.688596), (0.972477,0.842105), (1.24159,0.934211), (1.46177,0.973684), (1.67584,0.982456), (2,1)	Dmnl

[39] All lookup functions in the model are used in reference multiplicative formulations (Sterman, 2000).
[40] Lookup function values are (X,Y) pairs.

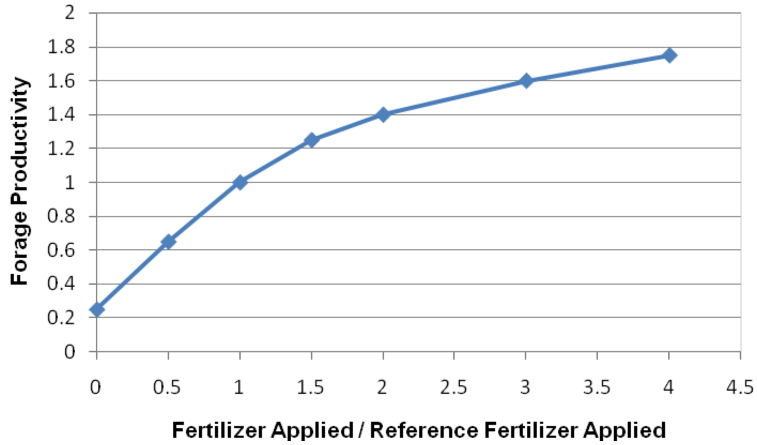
		
Effect of Forage Availability on Animal Forage Consumption	(-0.0675229,1.24211), (0.0572477,1.19474), (0.244404,1.12632), (0.577737,1.06842), (1,1), (1.23547,0.982456), (1.57847,0.973684), (1.97382,0.963158), (2.33211,0.963158)	Dmnl
		
Effect of Desired Cheese Production / Production Capacity on Capacity Utilization	(0,0), (0.100917,0.252193), (0.284404,0.498904), (0.550459,0.740132), (0.733945,0.860746), (1,1), (1.31193,1.08004), (1.48624,1.1239), (2,1.19518), (2.5,1.23), (3,1.25), (5,1.25), (6.97248,1.25439)	Dmnl



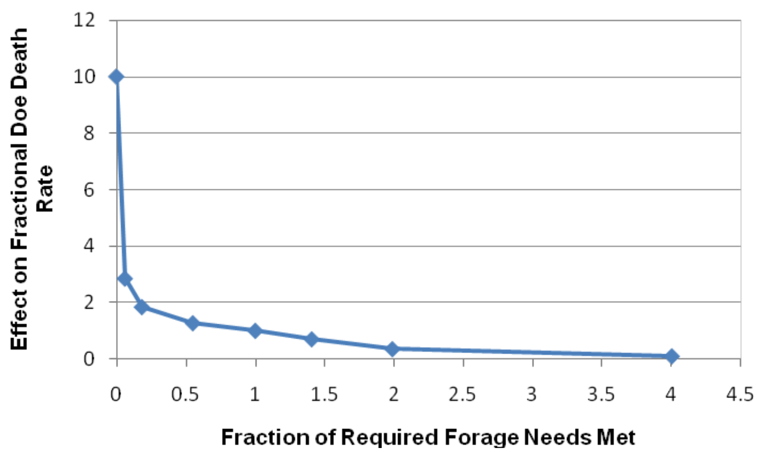
Effect of Perceived Required Forage Needs Met on Fertilizer Applications	(0,0), (0.110092,0.298246), (0.238532,0.587719), (0.366972,0.754386), (0.599388,0.894737), (1,1), (2,1.1), (3,1.15)	Dmnl



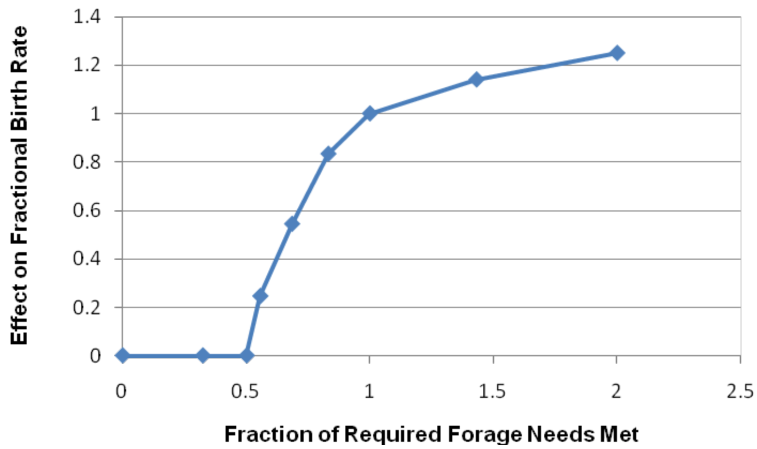
Effect of Fertilizer on Productivity	(0,1.5), (0.415902,1.46842), (0.568807,1.38947), (0.752294,1.28421), (0.88685,1.14211), (1,1), (1.5,1), (2,1)	Dmnl



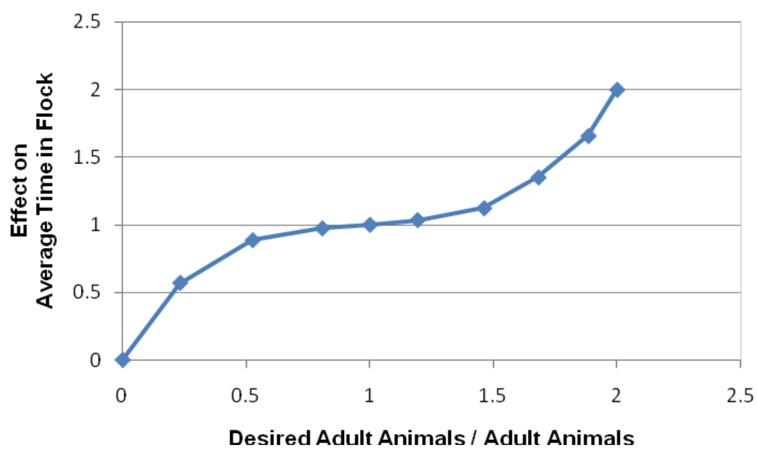
Effect of Forage Availability on Adult Doe Fractional Death Rate	(0,0), (0.330275,0.0789474), (0.599388,0.289474), (0.83792,0.614035), (1,1), (1.13761,1.24561), (1.37615,1.59649), (1.66361,1.83333), (2,2)	Dmnl



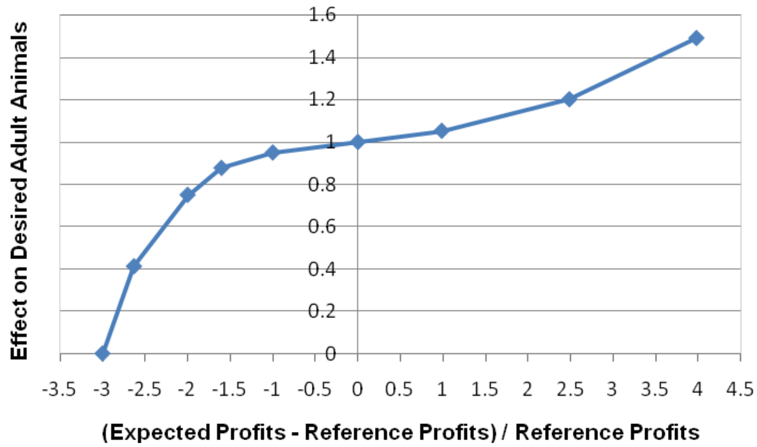
Effect of Forage Availability on Fractional Birth Rate	(0,10), (0.0611621,2.85088), (0.183486,1.84211), (0.550459,1.27193), (1,1), (1.40673,0.701754), (1.98777,0.350877), (4,0.1)	Dmnl



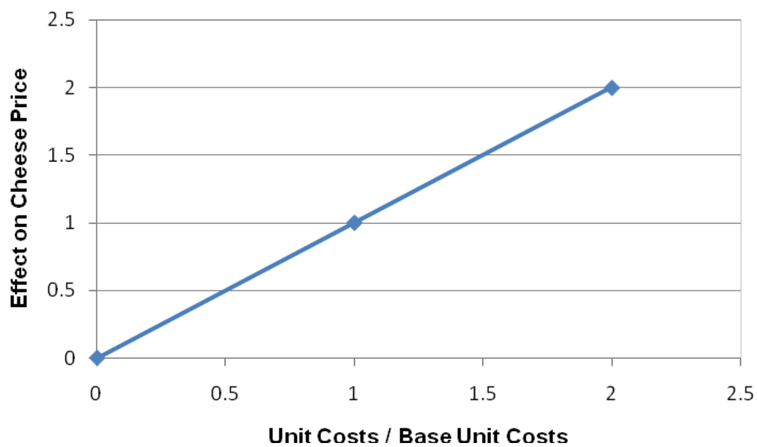
Effect of Desired Adult Animals/Adult Animals on Average Time in Flock	(0,0), (0.324159,0), (0.501529,0), (0.556575,0.245614), (0.685015,0.54386), (0.831804,0.833333), (1,1), (1.43119,1.14035), (2,1.25)	Dmnl



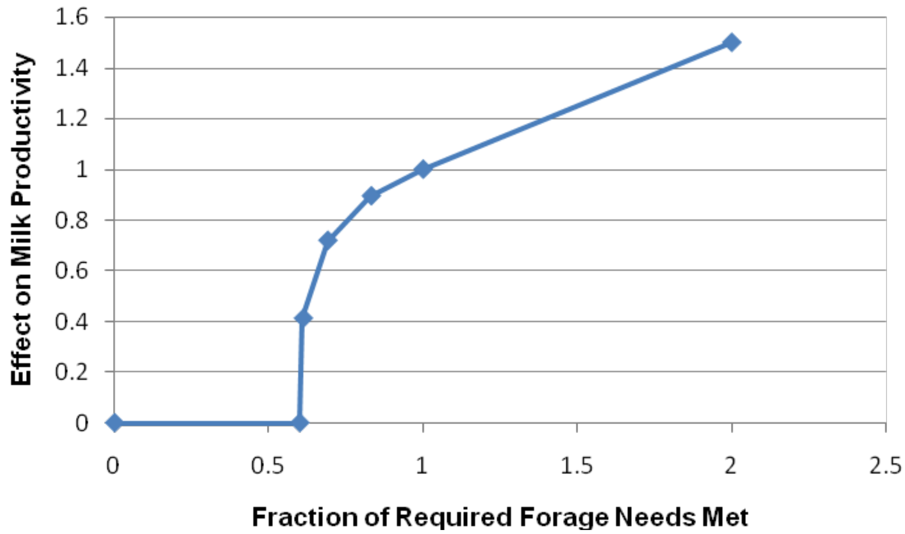
Effect of Expected Profitability on Desired Adult Goats	(0,0), (0.232416,0.570175), (0.525994,0.885965), (0.807339,0.973684), (1,1), (1.19266,1.03509), (1.46177,1.12281), (1.68196,1.35088), (1.88379,1.6578 9), (2,2)	Dmnl



Effect of Aged Cheese Costs on Aged Cheese Price	(-3,0), (-2.62997,0.412281), (-2,0.75), (-1.60245,0.877193), (-1,0.95), (0,1), (0.98471,1.05263), (2.48318,1.20175), (3.97554,1.49123)	Dmnl



Effect of Forage Availability on Milk Productivity	(0,0), (1,1), (2,2)	Dmnl



Effect of Expected Profitability of Milk on Household Milk Consumption	(0,0), (0.6,0), (0.611621,0.412281), (0.691131,0.719298), (0.831804,0.894737), (1,1), (2,1.5)	Dmnl

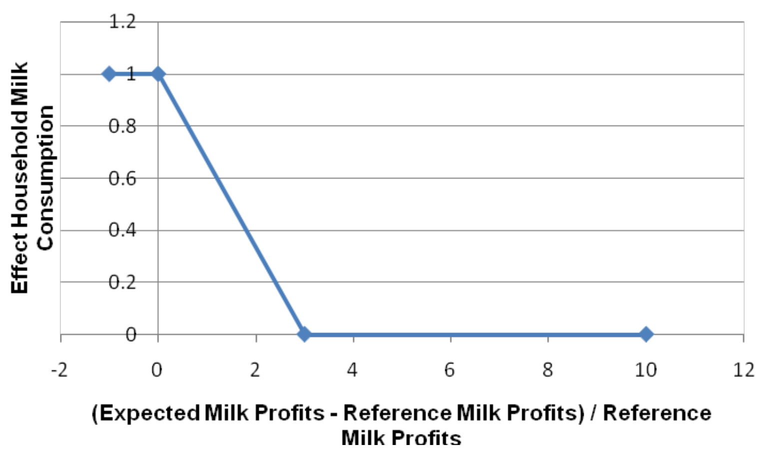


Table A2.5 Changes in key assumptions[41] for simulations

Simulation Name	Altered Parameters	Units	Default Parameter Value	Actual Parameter Value
Base	Cheese Coop Switch	Dmnl[42]	0 (off)	0 (off)

[41] Default parameter values and assumptions for the historical simulation are in Appendix 2, Table A2.3 and Table A2.4.
[42] Dmnl is an abbreviation for dimensionless.

Simulation Name	Altered Parameters	Units	Default Parameter Value	Actual Parameter Value
Cooperative[43]	Cheese Coop Switch	Dmnl	0	1
Optimal Market Size	Initial Population of Total Potential Buyers in Xico	Buyers	30	137
Optimal Milk Payment Price	Percentage Above Xico Milk Price Paid by Cooperative	Dmnl	0	0.224
No Payment for Raw Milk	Percentage Above Xico Milk Price Paid by Cooperative	Dmnl	0	-1
Optimal Milk Price No Dividends	Dividend Switch Percentage Above Xico Milk Price	Dmnl Dmnl	1 (on) 0	0 (off) 0.6368
2017 Dry Season Demand Shock	Demand Shock Demand Shock Duration Demand Shock Time	Kg Cheese /Month Month Month	0 0 0	200 6 120
2017 Rainy Season Demand Shock	Demand Shock Demand Shock Duration Demand Shock Time	Kg Cheese /Month Month Month	0 0 0	200 6 126
2017 Dry Season Cheese Price Shock	Price Shock Price Shock Duration Price Shock Time	Pesos/kg Cheese Month Month	0 0 0	50 12 120
2017 Rainy Season	Price Shock Price Shock Duration	Pesos/kg Cheese Month	0 0	50 12

[43] The default simulation is the historical simulation. In all other cooperative simulations, the cheese coop switch is set to 1 (on), which is not displayed in the table.

Simulation Name	Altered Parameters	Units	Default Parameter Value	Actual Parameter Value
Cheese Price Shock	Price Shock Time	Month	0	126
2010 Drought Shock	Normal Precipitation Switch	Dmnl	1	0
	2010 Drought Switch	Dmnl	0	1
2017 Drought Shock	Normal Precipitation Switch	Dmnl	1	0
	2017 Drought Switch	Dmnl	0	1
Combined 2017 Drought and 2019 Market Shocks	Normal Precipitation Switch	Dmnl	1	0
	2017 Drought Switch	Dmnl	0	1
	Demand Shock	Kg Cheese/Mo.	0	200
	Demand Shock Duration	Month	0	6
	Demand Shock Time	Month	0	144

Table A2.6 Recorded Seasonal Rainfall Data at Teocelo, Veracruz Weather Station (INIFAP, 2006a).

Month	Precipitation (mm)
January	58.66
February	56.10
March	79.66
April	78.24
May	146.56
June	351.69
July	297.20
August	283.46
September	376.96
October	193.91
November	104.51
December	67.51
Annual Total	2094.45

APPENDIX 3

MODEL EVALUATION

Model evaluation was completed using the model testing procedure outlined by Sterman (2000). The model was tested with and without[44] seasonal rainfall patterns imposed. Therefore, some sensitivity results may not reflect the same results that would be achieved if seasonal rainfall patterns are imposed. Section 3.2.6 contains comprehensive sensitivity testing results for the current model version.

Boundary Adequacy

The model boundary is adequate and consistent with the purpose of the model. This is reflected in the model boundary diagram provided in Table A2.1. Goat flock composition, feed resources (quantity), milk allocation, cheese production, cheese enterprise decisions, cheese production capacity, goat management decisions, and aspects of the local cheese market are endogenous. One notable exception is the exclusion of forage quality and nutrient availability from the model. Furthermore, seasonality is simulated as an exogenous input from available rainfall data. It directly affects forage production. The time horizon of 20 years is adequate to assess both the short-term and long-term implications of value-added goat cheese production. However, the time horizon can be lengthened as a test input to assess even longer-term impacts of value-added goats milk production.

[44] Non-seasonal tests were conducted on a preliminary version of the model.

Structure Assessment

The model is consistent with basic physical laws. However, the representation of forage resources is not consistent with the physical assumptions about how animals respond to the variability of forage quality. Forage quality was excluded for simplicity. A seasonal forage production proxy was created based on rainfall data to test variability in forage production.

It is also possible to obtain partial goats in the model. This permits more continuous behavior in lieu of modeling the biophysical processes as static events.

Dimensional Consistency

The model is dimensionally consistent without the use of parameters that have no real world meaning.

Parameter Assessment

Model parameters were estimated from available INIFAP data, personal correspondence with the INIFAP mountain microwatershed development team and from the Instituto Nacional de Ecología (2002). Most parameter values are close to actual real world values and have real world meaning. However, a varying degree of uncertainty exists for several parameters including delays and adjustment times. Thus, sensitivity testing was completed (Section 3.2.6) on all parameters. In addition, the structure and parameters used in the value-added goat cheese enterprise are hypothetical. Therefore, these parameters have a higher level of uncertainty than other parameters in the model.

Extreme Conditions

Numerous extreme conditions tests were conducted and equations are sensible at extreme values. For example, when the number of families was set to zero, the model became completely static and no production occurred. The model also performed adequately when the number of families was set at 10,000. Several floating point errors[45] due to division by zero were discovered and fixed by using Vensim's zero if divide by zero (ZIDZ) function.

Integration Error

The current time step of 0.0625 is adequate. According to Sterman (2000), the time step should be one-fourth to one-tenth as large as the smallest time constant in the model. The smallest time constant in the model is 0.25 months. The time step was halved several times to evaluate behavioral changes. Model behavior was relatively unaffected except for slight variation due to added integration error with the smaller time step. Larger time steps were also tested, but behavior changed more substantially when the value was above 0.0625 until uncharacteristic model behavior and a floating point error occurred with a time step interval of one.

Behavior Reproduction

The model endogenously approximated the hypothesized behavior of the system under normal and extreme conditions. The assumed reference mode behavior was reproduced given current model structure. No behavioral comparisons were made to actual data.

[45] Vensim® defines errors induced by division by zero as "floating point errors."

Sensitivity Analysis

The model was numerically, behaviorally, and policy-sensitive to changes in various parameters (Section 3.2.6). Behavior and policy-sensitive parameters merit further evaluation to assess their importance and criticalness to model behavior. Policy-sensitive parameters included flock makeup, cheese yield, milk productivity, production costs, milk consumption, raw milk price, and market demand.

Surprise Behavior

The most notable surprise behavior was encountered during a sensitivity test of the kids per parturition parameter. The variable was set to test between one and two kids per parturition. Intuitively, fewer kids per parturition would decrease flock size over time. However, it produced further growth in the flock over time. The smaller count of young goats in the flock consumed less milk, which left more milk for income generation. As a result, very slight increases in profitability were achieved with fewer young goat births, and producers increased the adult goat purchase rate to augment the size of the goat flock.