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Group Model Building to Assess Rural Dairy Cooperative Feasibility in South-Central Mexico

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Abstract

A group model building process based on system dynamics was developed to assess the potential of a cooperative manufacturing and marketing goat cheese in a community near Xalapa. The process identified important outcomes, key variables to consider, parameter values, and relevant scenarios. This information facilitated development of a dynamic simulation model including key biological and economic factors affecting cooperative success. Model analyses indicated that the cooperative potentially could increase community incomes while controlling risk under a range of environmental and market conditions. A system dynamics-based participatory approach can help inform *ex ante* assessment of potential development and agribusiness interventions.

Keywords: farmer-led dairy cooperative, participatory group model building, system dynamics, rural development, *ex ante* assessment

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Introduction

Although economic development has increased per capita income in many parts of the world, rural areas often lag urban ones even in countries with rapid growth (Besley and Cord 2007). As an example, rural communities in Veracruz, Mexico continue to confront multiple livelihood challenges, including food insecurity, unemployment, and low and variable agricultural incomes. The creation of income-generating opportunities is required to address these challenges. One approach that has been proposed and implemented is the identification of business models that are accessible to low-income households and that in many cases also serve their needs (e.g., London and Hart 2004). Approaches of this kind often involve the participation of intended beneficiaries, long advocated by many in the development community (e.g., Chambers 1983). However, assessing the feasibility of potential of agriculture-based business models is a complex undertaking. For example, one potential strategy to earn higher incomes is value-added agricultural products. Both biological and economic uncertainties can limit the potential of this strategy, especially for smallholders (Devaux et al. 2009). Smallholders may be unable to enter or to compete in high-value markets because of scarce market information, seasonal production shortfalls, inconsistent product quality, costly market access, and poor infrastructure (Goel and Bhaskarkan 2010, Njarui et al. 2010). These conditions increase transaction costs, especially for perishable foods (Devaux et al. 2009, Hellin et al. 2009, Markelova et al. 2009). They may also preclude participation in high-value markets (Staal et al. 1997, Holloway et al. 2000).

Farmer collective action is often proposed to surmount market barriers (Markelova et al. 2009). Value-added products manufactured and marketed by farmer groups or cooperatives may improve rural livelihoods by reducing uncertainty through collective bargaining, lower transaction costs, and higher average net incomes (Nicholson et al. 1998, Holloway et al. 2000, Devaux et al. 2009). For example, improved access to formal markets through dairy cooperatives raised smallholder productivity in Ethiopia and Kenya (D'Haese et al. 2007, Francesconi and Ruben 2007). Dairy cooperatives also increased the amount of milk marketed by smallholders in India (Alderman 1987). Cooperatives frequently provide services (e.g., extension information, animal vaccination, product quality control measures) that help improve productivity and product quality, thus further increasing the attractiveness of cooperative action (Owango et al. 1998, Devendra 2001). Successful job creation in rural communities further stimulates rural economies (Goel and Bhaskarkan 2010). Collective action may also facilitate economies of scale (Burli et al. 2008, Markelova et al. 2009). However, social and logistical challenges exist for collective marketing of perishable goods (Holloway et al. 2000). It is therefore important to assess whether costs may cancel or outweigh the expected economic benefits.

Most inhabitants in the Veracruz highland community of Micoxtla work in agriculture. Most Micoxtla families struggle with seasonal food and economic insecurity (INIFAP baseline survey 2006). After meeting household needs, the principal product sales are goat's milk, young goats for meat (cabrito), and eggs. Under an integrated rural development project operated by the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), community members identified growing demand for specialty products for the tourist trade in the nearby city of Xico (5000 residents, 5 km from Micoxtla) as a potential value-added opportunity. The community expressed interest in exploring production of aged goat's milk cheeses to increase household incomes, which would require startup capital beyond the capacity of individual families (Staal et al. 1997, Nicholson and Stephenson 2006). Additional risks from producing and marketing premium cheeses arise from dynamic biological, economic, and social processes including weather patterns, market access, and land availability for forage production. Collective action to form a farmer-led dairy cooperative, combined with startup extension services and training by INIFAP, could help reduce these risks. Consequently, the principal objective of this project was to assist the community and INIFAP advisors to assess the *ex ante* potential of a goat's milk cheese production and marketing business structured as a community cooperative. This assessment evaluates the potential of a cooperative to increase local incomes given biological and market risks, and identifies threshold values necessary to increase the probability of cooperative success. This analysis is best viewed as a first-stage assessment that can be extended and complemented with a subsequent more detailed assessment of market demands for the cooperative's product. A complementary objective was to demonstrate the use of participatory group modeling to evaluate the feasibility of rural agribusiness options.

Methods

Participatory Group Model Building

Although *ex ante* assessment of potential agribusiness interventions is common, rarely is it undertaken using participatory systems modeling. Consequently, this assessment employs a dynamic, participatory modeling method to evaluate many biophysical and economic factors important to cooperative success. This framework assesses the expected impact on community income when a proportion of milk produced in the community is purchased and manufactured by the cooperative into aged cheese for sale to Xico restaurants. We develop a simple cooperative management structure with the primary goal of raising member net incomes via milk purchases and periodic distribution of dividends to dampen the risk of too-low family incomes. In this first-stage assessment, the focus is the biological and market contexts and their effect on the cooperative business model, rather than the internal management dynamics of the cooperative.

The analysis uses a dynamic mathematical simulation model developed through participatory group efforts. A series of group learning and model building exercises were conducted with seven participants from INIFAP, including rural development agents and researchers, and a local university student. Three of the participants comprised the INIFAP micro-watershed development team, working closely with Micoxtla smallholders on agriculture and community development initiatives. The participants had diverse disciplinary backgrounds, including agronomy, agricultural science, rural sociology, statistics, GIS, and economics, and were accustomed to working as an interdisciplinary team. However, they typically operated without an overarching framework to allow assessment of intervention outcomes. The model-building process was one component of a three-month professional development short course on systems thinking and modeling requested by INIFAP, which affected the composition of participants. Although it is more typical for group modeling processes to include direct participation by all relevant stakeholder groups, the breadth of disciplinary backgrounds and the close working relationship between team members and the community allowed for adequate representation of the perspectives of many relevant stakeholder groups. For example, the initial idea for a community cooperative selling goat's milk cheese arose within the community itself.

Assisted by a trained facilitator, group modeling processes (Vennix 1996, Andersen and Richardson 1997) were used to elicit key information and conceptual frameworks from participants who completed five phases of the modeling process described by Sterman (2000). The course facilitator reinforced theoretical concepts to generate information for model development and to increase confidence in modeling as a tool for future INIFAP use. Participants first defined key rural development variables in Micoxtla, emphasizing the potentials for production and marketing of value-added agricultural products through a cooperative. The group next identified the expected behaviors of key outcomes over time, developing a conceptual model using feedback loop diagramming to account for observed behaviors. Subsequently, the principal stocks (states, accumulations) and flows (rates) constituting the functional cooperative framework were identified and structurally diagrammed. This information was used to structure the simulation model, providing likely ranges of parameter values, and establishing the main expected outcomes. The participants also evaluated the initial model structure. The software used to implement the model (Vensim®) includes iconic representation and a graphical user interface, which facilitated analysis of factors and scenarios of interest, also helping to identify key assumptions and potential modifications. Previous studies indicated that participatory group model building increases stakeholder engagement and understanding of complex problems (Vennix 1996). Thus, one objective of the group learning process was consensus building and ownership of the model and of potential interventions like the cooperative.

The resulting mathematical model uses a system dynamics (SD) modeling approach, which applies systems engineering concepts to interdisciplinary social, economic, and biophysical systems to help inform with insights about real-world problems (Sterman 2000). This approach has been applied to numerous business (Sterman 2000) and environmental settings (Ford 1999). However, despite the apparent benefits from SD methods there have been few applications in the international agricultural development arena (Nicholson 2007, Nicholson et al. 2011). Mathematically, SD models are systems of differential equations solved by numerical integration (Nicholson 2007). Vensim® software provides a visual interface representing feedback structure, explicit stock-flow (state-rate) structure, and quantitative decision rules characterizing the system. Vensim® also provides numerical and graphical outputs of key variables. The SD approach embraces dynamic complexity, where long-term outcomes from interventions may differ from those in the short-term (Nicholson 2007). This method permits simulation of likely outcomes from proposed interventions to assess key behaviors over time. It also facilitates evaluation of constraints and leverage points, thus potentially enhancing the effectiveness of agribusiness interventions. *Ex ante* assessment of establishing a dairy cooperative, or rural development strategies more generally, may forewarn about potential pitfalls and expected benefits, thereby increasing the odds of success (Thornton et al. 2003). A potential limitation of this approach is that data needed for the development of simulation models are often limited. Limited data also influence other approaches to *ex ante* evaluation, which is facilitated by methods like SD that help to identify key information affecting ultimate outcomes.

Model Overview and Scenarios

The biophysical and economic simulation model depicts the aggregate goat flock owned by 25 Micoxtla families and the potential activities of a farmer-led cooperative to manufacture and market aged cheeses. The model represents current income sources from the flock (sales of milk, *cabritos*, and culled does). Feed resources comprise forage and fodder, which constrain animal productivity. Forage yield varies seasonally with precipitation, and forage nutrient allowance influences reproduction, health, and milk. Mean monthly precipitation from 1961 to 2002 determines forage productivity, thus acting as a principal proxy for associated seasonal effects of rainfall, temperature, and solar radiation on forage production. Seasonal rainfall is more variable than temperature and photoperiod in Micoxtla (Appendix 5, seasonal weather patterns). In tropical regions with long dry seasons, water availability is frequently the most important factor influencing seasonal variation in animal productivity (Van Soest 1994). Consequently, rainfall is the dominant driver of forage nutrient supply to support animal production and reproduction. A review evaluating the effects of forage quantity and quality on animal productivity in pastureland systems demonstrated that for a wide range in forage dry matter per unit area of land, quantity accounts for 60 to 90% of the variation in animal productivity (in this case, average daily gain) (Sollenberger and Vanzant 2011). Increased forage quality would be required were cooperative managers to target increased milk yield per doe, assuming forage intake is not limited by quantity and animals have genetic potential for increased productivity (Mott and Moore 1985). Such productivity increases are not necessary for the initial stages of cooperative implementation. Thus, forage quality is assumed not to change over time or with the size of the community flock. Stochastic monthly rainfall selected from a distribution with values up to 2 SD from mean monthly values do not qualitatively affect the simulated outcomes regarding cooperative feasibility, so we report the results for deterministic simulations. Long-term drought has potentially larger impacts and is evaluated in detail below.

These biological modules collectively determine milk supply, a key input for the cooperative. Milk can be fed to young goats, consumed by the household, sold raw in Xico, or sold to the cooperative. A sinusoidal function generates uniform seasonal oscillation in the average raw milk price. The cooperative manufactures and markets cheese in response to the assumed logistic growth in demand (Bass 1969), incurring costs for the raw material (milk), processing, aging (storage), and marketing. Seasonal demand variation is not included in model scenarios. Earnings above costs by the cooperative can be invested in production capacity or in dividend payments to farmer members of the cooperative. The simple cooperative business strategy as determined by the participants makes capacity investment decisions (both replacement and expansion) based on expected sales and the availability of retained earnings. Dividends are paid after investments in capacity, retaining sufficient cash to cover two months of expected costs. We assume that cooperative members are motivated by dividend payments and will agree to provide the required milk as long as dividends are paid, up to limits of local production capacity and household consumption requirements. Because establishment can be a lengthy process, and to assess the potential unintended consequences arising from dynamic complexity, a 20-yr time horizon (2013 to 2033) is used to assess future behaviors after initiating operations. A more detailed description of model modules is in Appendices 1 through 5. Model evaluation (including parameter sensitivity testing) was completed using the set of tests described for SD models (Sterman 2000), and is reported in Appendix 6.

A plethora of factors could influence the potential of the cooperative to achieve its objective of increasing community incomes. The basic approach used herein is to compare the impacts of selected factors identified by the participants in the group model building exercise on outcomes these participants indicated would be important to the community. These outcomes include month-to-month and cumulative community income (farmer, household) from caprine activities and cooperative feasibility (assessed by the ability to maintain cash holdings, to maintain production capacity, and to pay dividends to members). The scenarios with the cooperative include comparisons to a baseline, which represents the likely future outcomes in its absence. The model is also used to assess a number of factors affecting the probability of its success, including production parameters, costs, and the number of buyers for aged cheese. Some of these factors (e.g., product price and costs) can be influenced by government policy, so this analysis accounts for selected policy effects, albeit in an indirect way. We do not analyze the effects of other government policies that may influence the success of the cooperative (despite the likelihood of policy changes over a 20-year time horizon) largely due to the challenges of determining *ex ante* their nature or timing. Other scenarios permit assessment of the impact on cooperative feasibility of large short-term reductions in milk production (e.g., drought that reduces feed supplies) and cheese demand. Results are depicted graphically, as is often recommended for analyses of dynamic systems (Sterman 2000), with selected results provided in summary tables.

Results and Discussion

Baseline and Cooperative Scenarios

The baseline scenario (Figure 1, black line) assumes continuation of the Micoxtla *status quo* in the absence of a cooperative. Monthly caprine income for the community is generally below 5000 pesos ($1 USD in 2012 = 13 Mexican pesos) and subject to large seasonal variation. Oscillation in net income arises primarily from fluctuations in forage supply caused by variations in precipitation (Appendix 5, seasonal weather patterns). Results are also influenced by exogenous seasonal fluctuations in the price of raw milk, ranging from 4.5 pesos kg^{-1} during the dry season to 3.5 pesos kg^{-1} during the rainy months. Due to diminished milk production during the dry season, caprine activities are unprofitable for about two months each year (April and May). The simulated cumulative net income for the community flock during the 20-yr time horizon is about 910,000 pesos, from sales of milk, *cabrito*, and culled animals. Milk accounts for 78% of total income, followed by *cabrito* (19%) and culls (3%). This income pattern matches that observed by the INIFAP team and reported by Micoxtla producers.

Establishment of the cooperative requires an initial investment to manufacture and to market aged cheese. Initial working capital and equipment investment costs would be approximately $10,000 USD based on other small-scale dairy processing costs (Holloway et al. 2000, Nicholson and Stephenson 2006, Nicholson et al. 1998). Although this investment is clearly important, we assume that the community would be able to obtain the required funds from government sources, grants, or development agencies. This initial investment occurs in January 2015. Following initial investment, the cooperative manufactures and markets cheese in response to logistic growth in demand (Bass 1969) from 2015 to 2022. The cooperative invests in additional production capacity as permitted by retained earnings. The cooperative initiates dividend payments to members in 2017, and payments increase to peak levels by 2022. Dividend payments in the cooperative scenario provide monthly net incomes for the community approximately three years after initial investment. This delay in realizing improvements in income may prove important to community participants in the cooperative and must be conveyed to potential members prior to startup to prevent frustration or member abandonment (Henehan 2001).

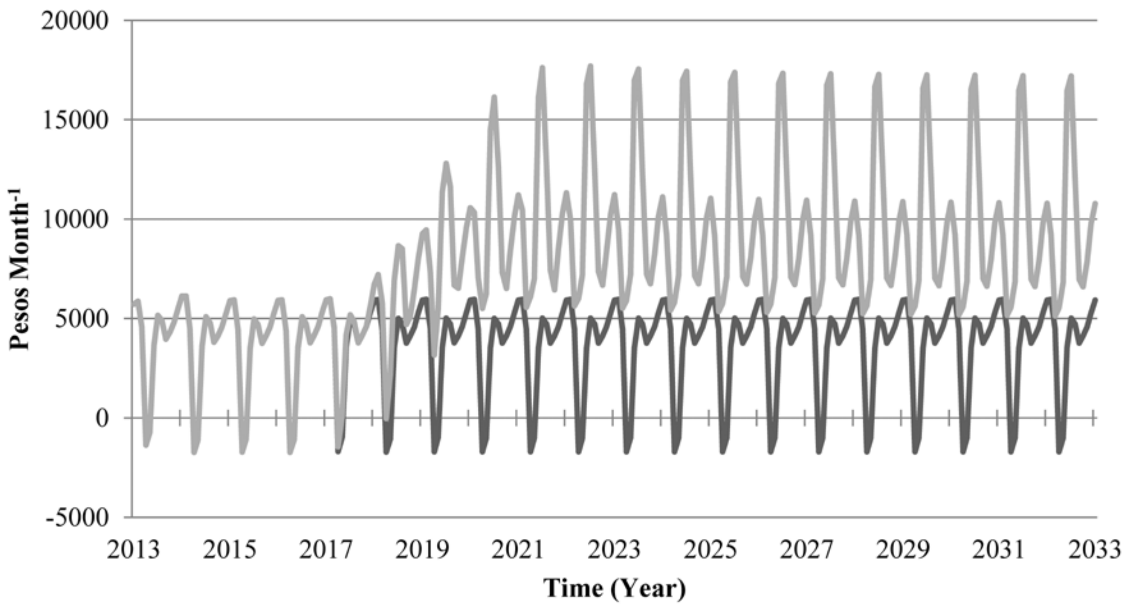

Figure 1. Monthly net cash operating income of community caprine operations for cooperative (grey line) and baseline (black line) scenarios

Cooperative operations result in greater average monthly net income for the community beginning in 2018 (Figure 1, grey line). The cooperative cash balance is positive throughout the horizon assuming an initial working capital of 30,000 pesos (Figure 2). Community incomes for the baseline and cooperative simulations differ primarily due to dividend payments by the cooperative, but also from growth in goat flock size. The cooperative also has the capacity to eliminate negative community net cash operating incomes from caprine operations during the dry season. Dividend payments would be made during periods of previous low or negative net cash operating incomes as a result of delays in cheese maturation and sales. The cumulative net income from community caprine activities is 1.936 million pesos, an increase of more than 1.0 million pesos over the baseline estimate for this 20-yr time horizon. This suggests significant potential for a cooperative to increase net incomes in the community under the assumed conditions. Importantly, the cooperative incurs losses for slightly more than three months each year (mid-May to mid-August; indicated by reduction in the retained earnings during these months, Figure 2).

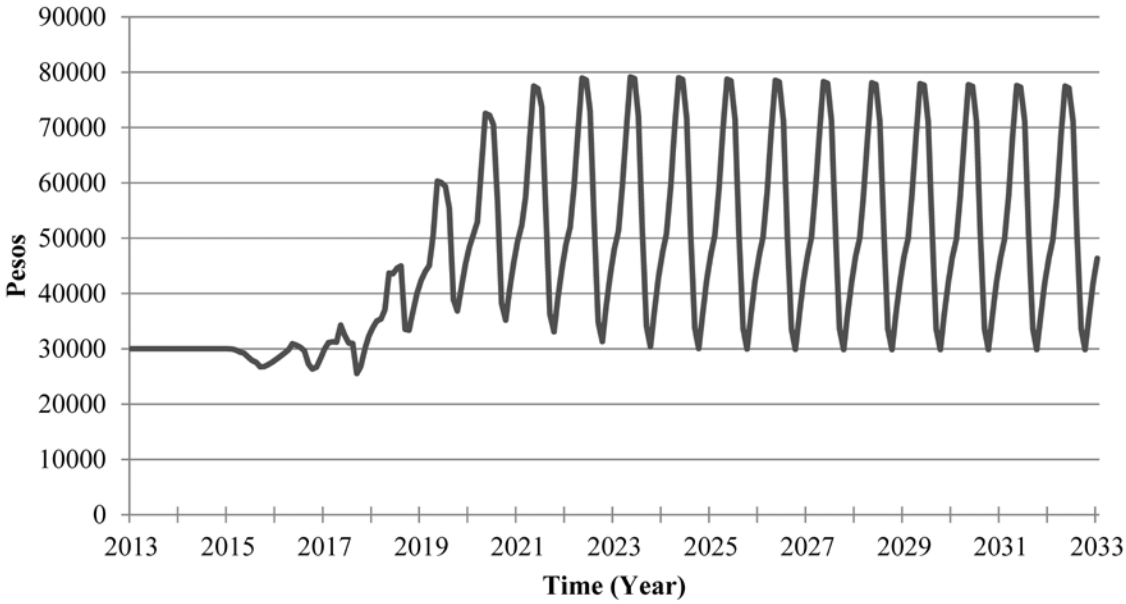

Figure 2. Cooperative cash balance for cooperative scenario

Factors Influencing Success of the Cooperative

The foregoing analysis indicates potential for the cooperative to increase Micoxtla incomes under the assumed conditions, but numerous factors may jeopardize this potential. Accordingly, we determined the threshold values that would preclude dividend payments, reduce cheese production capacity, or that would result in a negative cash balance. These threshold values are also expressed as percentage changes from assumed baseline values (Table 1). This analysis suggests cooperative feasibility over a wide range of assumed values for key factors.

Any business must develop an adequate customer base to achieve financial success. Although a thorough market evaluation was not undertaken in this first-stage assessment, a threshold analysis was developed to determine the minimum market size that would be required to allow dividend payments. In this case, the number of minimum required regular buyers is small (two, Table 1). Although this does not negate the need for a more thorough market assessment, it suggests that development of a customer base may not be the most constraining factor to successful cooperative development. In fact, the cooperative's ability to pay dividends is most sensitive to a reduction in the base price of cheese, for which a 24% reduction from the observed market value of 120 pesos kg^{-1} would be sufficient to undermine economic survival of the cooperative. For simplicity, univariate changes to values were assumed for these threshold analyses. However, multivariate analyses of these factors also suggest that the cooperative would be feasible even with multiple values assumed near the identified thresholds.

Table 1. Parameter threshold values that would prohibit dividend payments to producers, maintaining production capacity, or maintaining a positive cash balance

Factor	Threshold value	% Change from base value
Total potential buyers in Xico, number	2	-93.3
Cheese yield, kg cheese (kg milk)$^{-1}$	0.06	-40.0
Maturation time for cheese, months	10	+150.0
Production cost, pesos (kg cheese)$^{-1}$	39	+290.0
Storage cost, pesos (kg cheese * month)$^{-1}$	12	+140.0
Marketing cost, pesos (kg cheese)$^{-1}$	41	+310.0
Base cheese price, pesos (kg cheese)$^{-1}$	95	-24.0
Premium over local milk price, pesos kg^{-1}	5.2	+33.3
Initial cash holdings, pesos	5,000	-83.3

Rapid growth in demand could also threaten cooperative feasibility if the cooperative is unable to increase production quickly enough to remain a reliable supplier to the tourist market in Xico. We therefore assess the maximum annual growth rate in orders that can be filled by the cooperative over the simulated time horizon within the milk production capacity of the community goat herd and cooperative processing capacity. The cooperative could meet more than 90% of the demand during seasonal periods of high product inventory for compound annual growth rates of sales up to 11% per year beginning in 2017. Rapid demand growth causes additional variation in cooperative cash flow, but increases cumulative community net incomes. Although this analysis only considers milk supply from a single community, cooperative membership expansion to include additional smallholders in Micoxtla and nearby regions might be attractive given the benefits of cooperative participation.

Production and Demand Shocks

Because the cooperative's production and marketing environment is uncertain, it is important to determine the impact of potential shocks on community net income and cooperative feasibility. Although many such shocks could be important, this assessment illustrates selected biological and economic cases: a shock to production (drought) and demand for the product (e.g., an economic shock to the Mexican economy that reduces tourism). The timing of these shocks is important. Both shocks occur in 2017 during the growth phase and prior to the initiation of dividend payments. This is an especially vulnerable phase for the cooperative. For the production shock, we assume a two-year reduction in rainfall to 40% of normal to test the impact of an extreme production shock (the largest observed single-year reduction in rainfall during 1961 to 2002 was 63% of normal). The demand shock assumes that demand falls to 50% of its previous level for a period of two years. These shocks reduce community income and cooperative cash balance (Figure 3 and Figure 4), but do not preclude dividend payments or result in negative cash balances. Moreover, the impact of the production shock on monthly income is less for a cooperative than without it (Table 2). This finding also suggests that the cooperative may be robust in the face of unexpected biological and market developments (e.g., climate change).

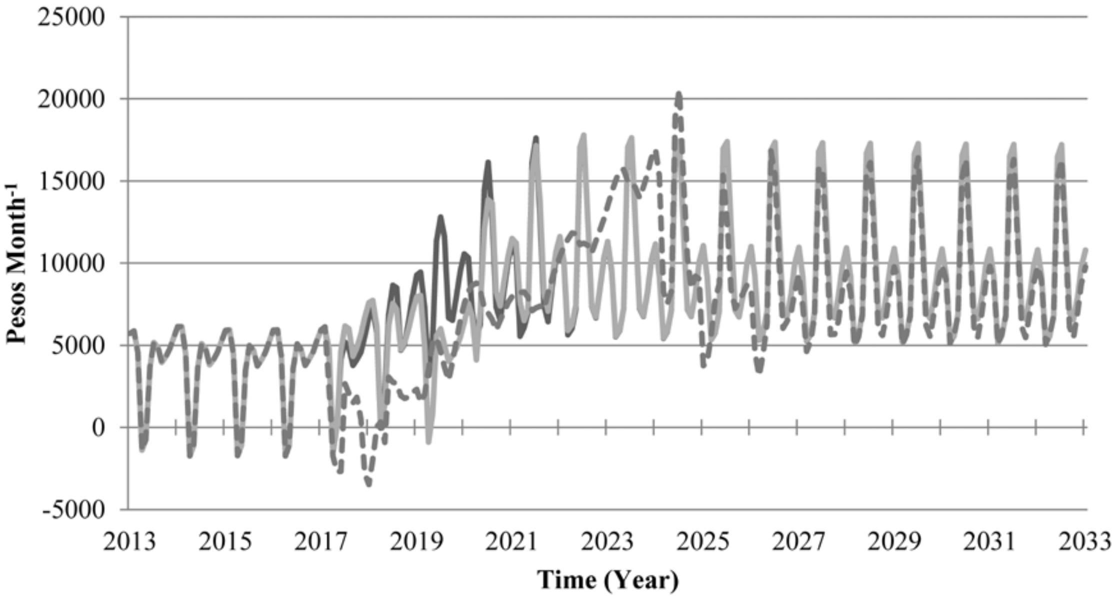

Figure 3. Monthly net cash operating income of community caprine operations for cooperative scenario (black line), the 2017 demand shock (grey line) and the 2017 production shock (dashed line)

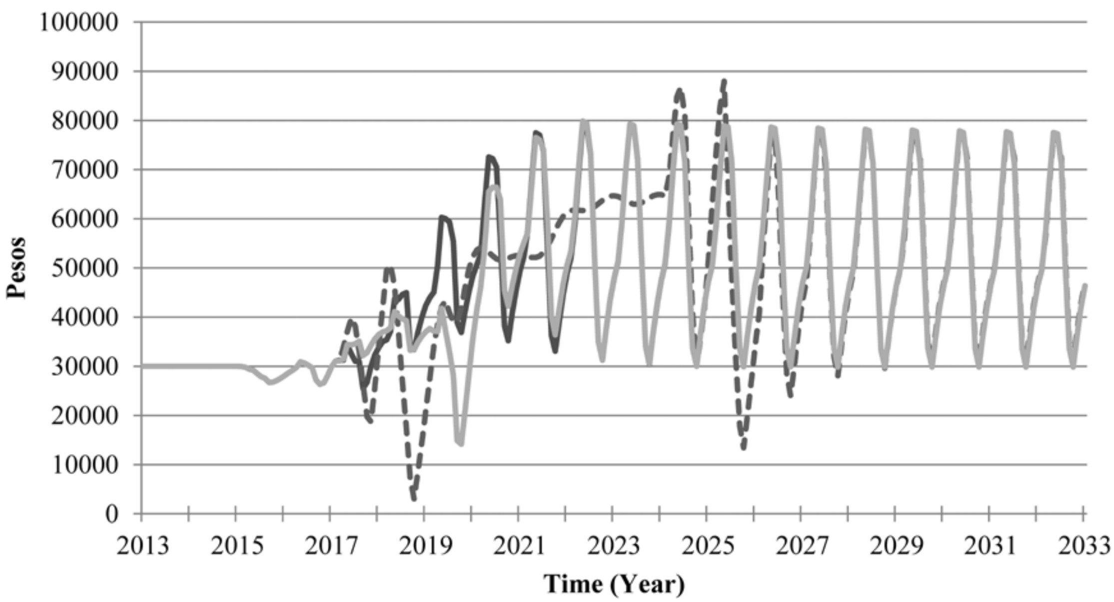

Figure 4. Cooperative cash balance for cooperative scenario (black line), the 2017 demand shock (grey line), and the 2017 production shock (dashed line)

Table 2. Key cumulative outcomes for reported simulation scenarios

Scenario	Cumulative Net Income (10^6 pesos)	% Change from Baseline	% Change from Cooperative	Cumulative Dividends (10^6 pesos)	Cooperative Average Cash Balance (pesos)	Cooperative Minimum Cash Balance (pesos)
Baseline	0.910	0	-53.0	N/A	N/A	N/A
Cooperative	1.936	+112.8	0	0.944	46,807	25,496
Demand shock	1.895	+108.3	-2.1	0.906	46,044	14,129
Production shock	1.741	+91.4	-10.1	0.943	46,325	3,004
Production shock, No cooperative	0.719	-20.9	-62.8	N/A	N/A	N/A

Conclusions

The results of this group-developed simulation model indicate that establishment of a cooperative to produce and market cheese has potential as a strategy to increase net incomes of caprine owners like those in Micoxtla. Furthermore, the cooperative appears to be resilient to variations in key biological and market parameters, and to production and demand shocks of extended duration. Short-term and moderate market demand reductions and biological shocks do not markedly alter long-term trajectories for net income or cooperative cash flow. Following recovery from shocks, the behavior of relevant financial variables is similar to behavior in the absence of shocks. Nonetheless, other factors merit consideration to assess cooperative implementation.

First, a lack of capital to invest in market feasibility studies, business plan development, and infrastructure in the startup phase may preclude effective cooperative formation (Henehan 2001). In this case, initial investment is necessary to commence operation of the cooperative, and this likely would need to be externally provided. We estimate that initial working capital and equipment investment costs would total less than $10,000 USD based on observed small-scale dairy processing costs (Holloway et al. 2000, Nicholson and Stephenson 2006). With this investment, the cooperative could return more than 900,000 pesos ($69,230 USD, undiscounted) in dividends paid to farmers from 2017 to 2033.

Second, training is required to assure timely delivery of a quality product. Cooperative managers need to be identified and trained in hygienic cheese processing, facilities repair and maintenance, and business management practices (e.g., accounting, customer relations, member management, and marketing). The training program could be organized and delivered by INIFAP or another development organization. Third, effective cooperative management and bylaws are fundamental to success (Fulton and Hueth 2009). Well-trained leaders and managers are needed to avoid risks from corruption and lack of farmer participation. An important risk is limited ability to attract a sufficient milk supply, partly due to the lag between initiating the cooperative and payment of dividends under assumed decision rules. This analysis indicates that during startup, several years may be needed for the cooperative to achieve solvency. This is a challenge because members may discontinue participation due to a lack of economic benefits during this period. If the cooperative were to experience financial difficulties, especially during the establishment period, this could affect the future willingness of farmers to participate. This process likely could be usefully assessed with agent-based models of cooperative management (North and Macal 2007), but few agent-based analyses of agricultural cooperatives have been undertaken to date.

Longer-term structural changes in supply and demand could also affect cooperative feasibility, forcing managers to reassess the cooperative business model and opportunities for participant expansion. On the supply side, cooperative members may identify other more remunerative activities with their existing resources over the long time horizon analyzed. For the cooperative to be successful in the long term, it must also determine the most appropriate strategic responses to changes in market demand, including both the volume demanded and the types and variety of products. Finally, although the cooperative can increase community incomes even for a relatively small market (two buyers, see above discussion), a detailed study of market demand for aged cheese would be required to identify specific buyers and the volume and seasonal patterns of sales. During group model building activities, INIFAP participants identified market information as a major limitation and a priority activity before cooperative establishment. Although these represent significant challenges, traditional market assessment methods and additional group model building efforts can be used to assess these factors and to suggest potential strategies.

On the other hand, this modeling analysis does not fully represent other potential financial or social benefits from cooperatives for Micoxtla or other communities like it. Farmers hold more collective bargaining power as a unit in the market place than as individuals (Nicholson et al. 1998, Holloway et al. 2000, Devaux et al. 2009). A dairy cooperative may also reduce transaction costs for its constituency (Staal et al. 1997, Holloway et al. 2000). Although the current model does not differentiate transaction costs for fluid milk sales in Xico and the cooperative, this may be another motivation for cooperative membership. Production of additional value-added products in rural communities like Micoxtla could further mitigate the risks associated with agricultural livelihoods. A similar approach to the one adopted in this paper could be applied to assess these products or to assess other options for agribusiness development interventions.

Group model building based on SD methods has the potential to improve the efficacy of international agribusiness development initiatives. The participatory activity was important for four principal reasons. First, the group identified community priorities and opportunities. For example, the community strongly believed that any value-added activities should be undertaken as a community (cooperative) effort rather than by a small number of entrepreneurs, and this was reflected in a key assumption of the modeling effort. The group also identified the potential for the specific product, goat's milk cheese, based on their experience with marketing opportunities in Xico. Second, the interdisciplinary group of participants contributed to the development of the specific structure of the modules, but also engaged in vigorous discussions about how much detail was required to adequately capture the (qualitatively) observed behaviors. Thus, they identified potential areas for model simplification that were reflected in the model structure described above. Third, inclusion of the participants in model building has been shown in previous studies (Vennix 1996, Andersen and Richardson 1997) to enhance group learning, consensus building, and confidence in the expected outcomes of potential interventions. Although this study does not include a more formal evaluation of these outcomes, course evaluations indicated that these outcomes occurred. Changes in the structure of INIFAP programs, including a reduction in resources for the micro-watershed team's activities, occurred since the time of the study. This probably prevented implementation of a cooperative in Micoxtla subsequent to the participatory group model building effort. Finally, in contrast to typical group model building undertakings (Vennix 1996, Andersen and Richardson 1997), INIFAP participants benefitted from instruction in systems thinking and system dynamics modeling. Consequently, participants acquired skills necessary to use the model and to potentially modify it or develop their own tools for *ex ante* assessment of agribusiness interventions. The present application, undertaken with a leading research and development institution in Mexico, demonstrates the contributions of these methods to research and development programming. The net benefit could yield better understanding about the pathways of proposed interventions, their benefits and pitfalls, and better informed investments by donors.

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Appendix 1. Core Model Structure and Module Overviews

The model comprises eight linked modules that are described below: 1) community goat flock, 2) forage resources, 3) milk allocation, 4) dairy cooperative management and decisions, 5) cooperative productive capacity, 6) cooperative aged cheese manufacture, 7) market for aged cheese, and 8) net income expectations and decisions for goat producers. Module descriptions are complemented by key model equations (Appendix 2), model parameter values (Appendix 3), lookup tables (Appendix 4), seasonal weather patterns (Appendix 5), and model evaluation (Appendix 6).

Community Goat Flock

The goat flock module tracks the size and composition of the aggregate community flock (Figure A1). The stock-flow structure consists of a doe aging chain divided into three stocks: *cabritas* (young does), weaned *cabritas*, and adult does. An additional stock of *cabritos* (young bucks) contributes to the goat production stock-flow structure, but is not included in the doe aging chain because *cabritos* are either sold or consumed locally. Primary management decision rules associated with the goat flock include reinvestment in adult does (animal purchases) and variation in the adult doe culling rate.

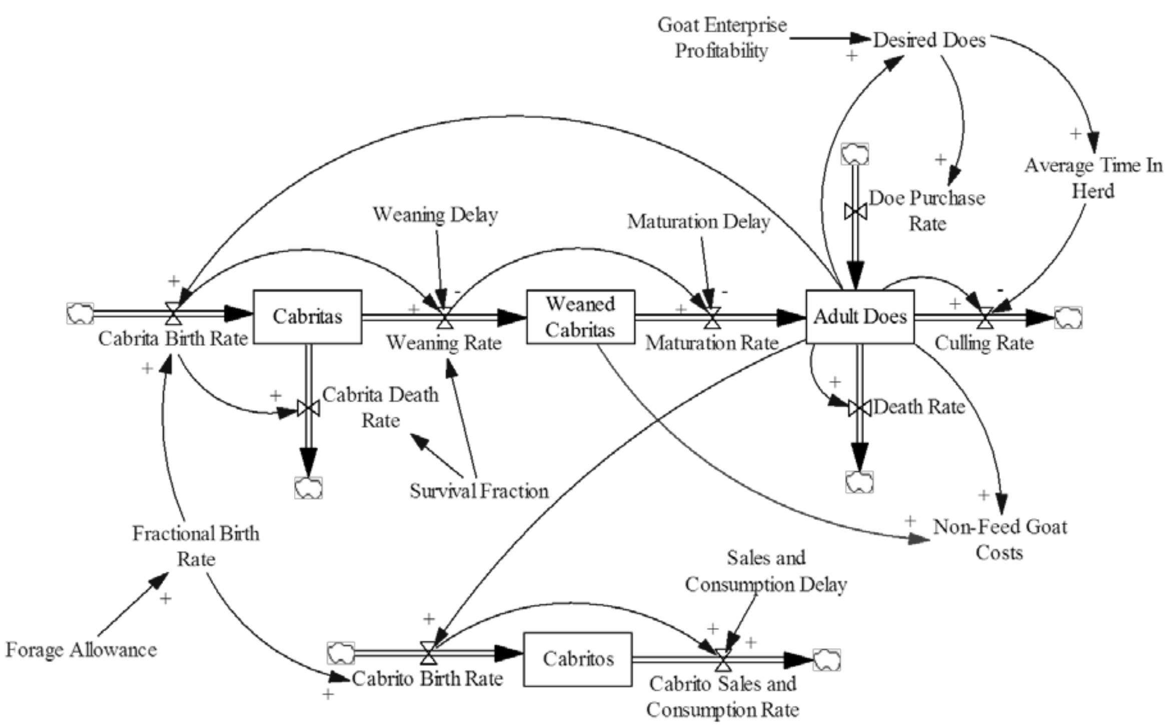

Figure A1. Simplified goat flock stock-flow structure consisting of four stocks to represent flock management

The fractional birth rate (Appendix 2, Table A1, Eq. 1) varies based on fulfillment of required forage needs (effect of forage allowance) through a reference multiplicative formulation[1]. The rate is uniformly distributed so that 50% of goat kids are males and 50% are females. The *cabritas* stock is affected by one inflow (*cabrita* birth rate) and two outflows (death and weaning rates). The weaning rate, an intermediate flow between the *cabritas* and weaned *cabritas* stocks, is a third-order delay of the *cabrita* birth rate and depends on the constant average weaning age. The weaned *cabritas* stock contains 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 to complete maturation to adulthood, which is depicted by entry into the stock of adult does. The age at first parturition is just over two years. We assume that all adult does produce milk.

The stock of adult does contains an additional inflow, purchased animals, and two first-order outflows, the rates of culling and mortality. We assume that Micoxtla producers make decisions about flock composition based on enterprise profitability. The culling rate (Appendix 2, Table A1, Eq. 4) changes with average time in the flock, a variable that is a function of the ratio of desired adult does to actual does (Appendix 4, Table A3). When desired adult does exceed actual adults, producers purchase does (Appendix 2, Table A1, Eq. 5) and decrease the culling rate (Appendix 2, Table A1, Eq. 3, 4). The desired adult does variable (Appendix 2, Table A1, Eq. 2) is defined by a reference multiplicative formulation that adjusts based on the actual number of adult does and expected net income of the goat operation (Appendix 4, Table A3). Does are purchased when sufficient cash is available and the desired number exceeds the actual count of adults. The desired does and doe purchase formulations are adapted from the production capacity formulation in Sterman (2000).

The fractional mortality rate determines the adult doe mortality rate as a function of several parameters so that the model initializes in dynamic equilibrium. The fractional rate also varies according to the effect of forage allowance (forage dry matter per animal unit) via a reference multiplicative formulation (Appendix 4, Table A3). We assume all culls can be sold at a fixed price and all animals in the stock of adults (adult does and weaned *cabritas*) incur monthly non-feed costs. Therefore, sales of culled animals and monthly non-feed costs affect the monthly net cash operating income of community caprine operations.

The fractional birth rate inflow and goat sales and consumption outflow affect the *cabritos* stock. The outflow is a third-order delay of the inflow. We assume that all *cabritos* are either sold or used for household consumption, and all that are not consumed are sold. The number of animals sold and the constant *cabrito* price determine *cabrito* sales revenues. Animals 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 own breeding bucks lend them to other producers. Non-buck owners sometimes pay low breeding fees that are ignored and excluded from the model boundary.

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[1] 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 default conditions. The effect uses a lookup function (see Appendix 4, Table A3 for all model lookup functions).

Forage Resources

The forage resources module (Figure A2) generates a nonlinear physical capacity constraint to the size of the goat flock. An important variable linking it to the community goat flock module is fractional forage needs satisfied (Appendix 2, Table A1, Eq. 7), which is derived from forage mass per caput (Appendix 2, Table A1, Eq. 6). The ratio of forage mass per caput to reference forage mass per caput defines the fraction of forage needs that are met (Appendix 2, Table A1, Eq. 6 and 7). This fractional forage condition (effect of forage allowance) nonlinearly affects the birth rate, adult goat mortality, milk production, and desired forage resources via their respective reference multiplicative effect formulations in other modules (Appendix 4, Table A3). This forage resources formulation assumes forage quality does not change over time or with the size of the community flock. Management decisions in this module include fertilizer applications to forage crops and land area in forage production. Both generate production costs in the form of fertilizer costs (Appendix 2, Table A1, Eq. 14) and land costs (Appendix 2, Table A1, Eq. 15). Labor costs (Appendix 2, Table A1, Eq. 16) are a function of forage produced. The sum of labor, land, and fertilizer costs determines forage production costs (Appendix 2, Table A1, Eq. 17).

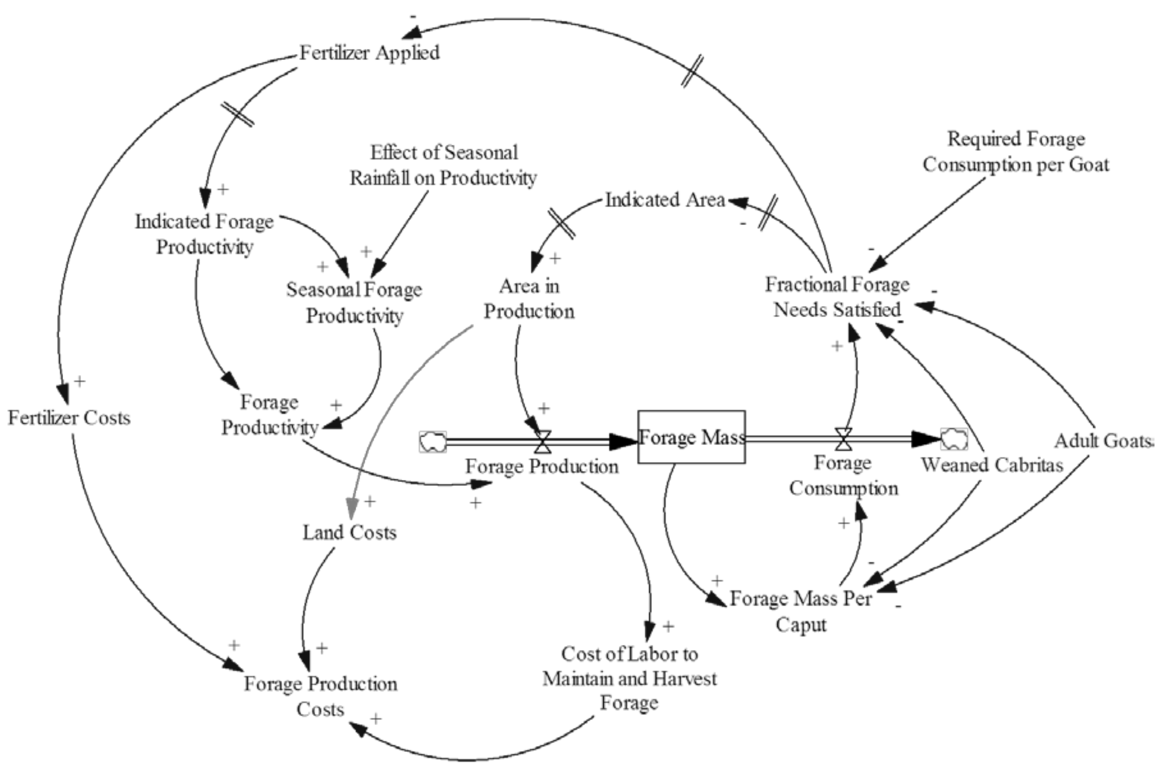

Figure A2. Simplified forage stock-flow structure consists of multiple balancing feedback loops that regulate forage production and consumption

The forage resources component of the model consists of one stock, forage mass, with its production inflow and consumption outflow. We assume that farmers desire to increase forage production through productivity increases and land area expansion when forage resources are perceived to be insufficient. Both land productivity and land in production are anchored on their reference values in reference multiplicative formulations (Appendix 4, Table A3). Indicated land area changes via a reference multiplicative formulation so that more land is desired when forage resources are perceived to be inadequate (Appendix 2, Table A1, Eq. 8). Furthermore, producers increase fertilizer applications (Appendix 2, Table A1, Eq. 9) when forage productivity is inadequate in an attempt 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. The indicated forage productivity variable (Appendix 2, Table A1, Eq. 10) calculates productivity changes from fertilizer applications via a first-order delay formulation with a three-month delay time.

Indicated forage productivity or seasonal forage productivity (Appendix 2, Table A1, Eq. 12) determines actual forage productivity (Appendix 2, Table A1, Eq. 11). Seasonal land productivity changes with the pattern of rainfall though the effect of seasonal rainfall on productivity (Appendix 2, Table A1, Eq. 13). Average yearly rainfall patterns (Appendix 5, Table A4) from the climatology station in Teocelo, Veracruz from 1961 to 2002 provide a proxy for seasonal variation in forage productivity (INIFAP 2006). The ratio of average individual monthly rainfall to overall average monthly rainfall affects forage productivity in a multiplicative formulation (Appendix 2, Table A1, Eq. 12).

Forage consumption (Appendix 2, Table A1, Eq. 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 mass per caput to reference forage mass per caput (Appendix 4, Table A3).

Milk Allocation

The milk allocation module (Figure A3) tracks fluid milk for *cabrito* and *cabrita* consumption, for household consumption, and for sales income. Stocks of adult does, *cabritos*, and *cabritas* link it to the goat flock module. The effect of forage allowance also affects milk output and links the milk allocation module to the forage resources module.

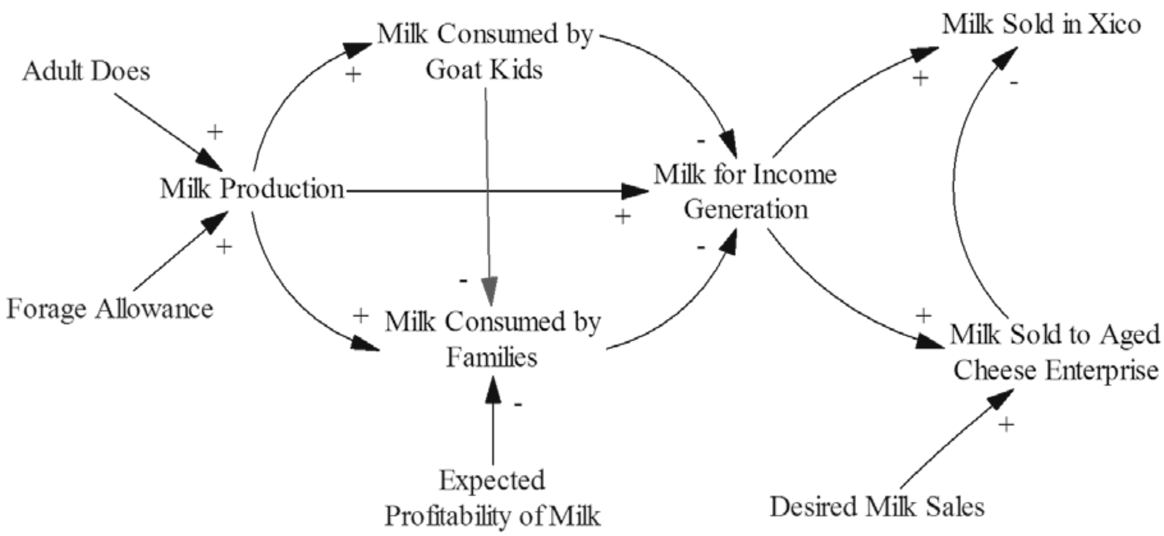

Figure A3. Simplified structure for milk allocation consisting of fluid milk consumption by goat kids and the families raising them, with surplus milk allocated for income generation and sold in Xico or to the aged cheese cooperative

Reference multiplicative formulations define the nonlinear relationships in variables for the amount of milk consumed by the household and daily milk yield per doe (Appendix 4, Table A3). Milk for household consumption decreases when milk sales income surpasses the reference value. Milk for *cabrito* and *cabrita* consumption varies with the number of young goats. Producers do not restrict milk consumed by kids. Thus, a constant daily amount per kid is assumed. Milk production also varies based on forage allowance and total adult does.

Milk remaining after consumption by kids and by the household is sold (Appendix 2, Table A1, Eq. 20). The model begins with all milk available for income generation activities being sold in Xico. An initial investment to establish productive capacity is required for milk to be allocated to produce aged cheese. This initial investment occurs in January 2015, two years after the simulation start time. We assume that producers will first fill cheese cooperative demand before selling excess milk in Xico (Appendix 2, Table A1, Eq. 21 and 22). Transaction costs are not considered for farmers.

Dairy Cooperative Management and Decisions

The dairy cooperative module (Figure A4) depicts cooperative management decisions and impacts on cooperative cash balance, and is independent of animal production and milk sales. The structure tracks the cooperative income statement, which is the difference between premium cheese sales revenue and the sum of raw milk costs (at the local market price under baseline conditions) and cheese production, storage, and marketing costs. Cooperative income and expenses depend on cheese manufactured. Labor and management are included in production and marketing costs. Thus, the overall measure of financial performance for the cooperative is net income.

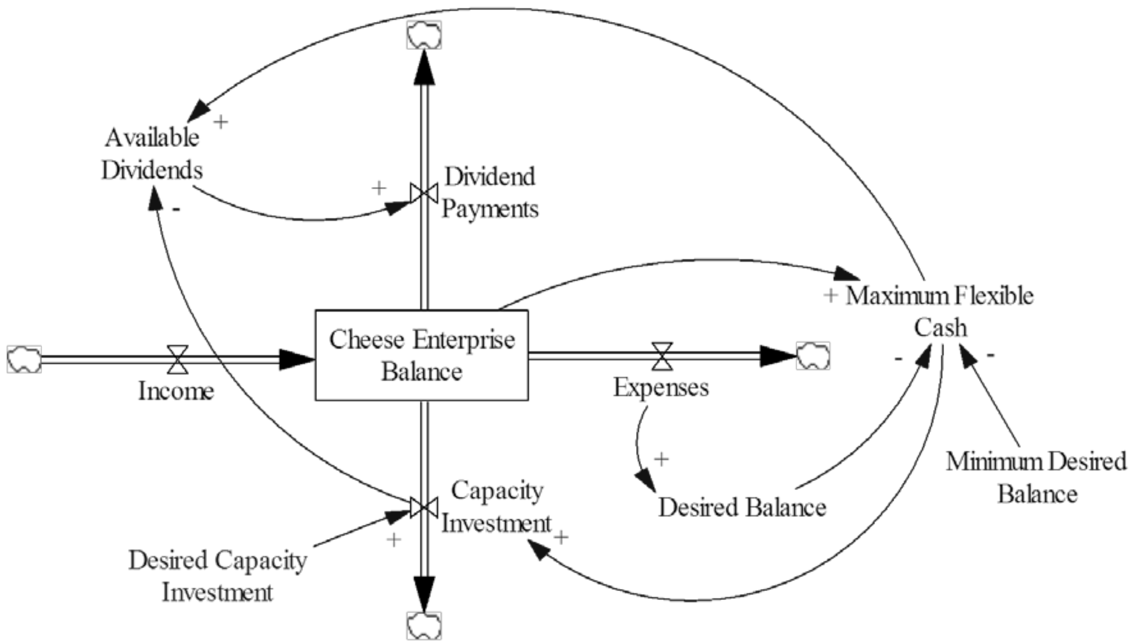

Figure A4. Simplified single stock structure for cheese cooperative decisions and cash balance, consisting of income minus expenses and accounting for dividend payments and capacity investments given assumed cooperative management policies

The cash flow statement forms the core structure of the module. It accumulates cash from net income, which can be dynamically allocated to invest in productive capacity. As is the case with some farmer-led cooperatives (Goel and Bhaskarkan 2010), we assume that the objective of the cooperative is to maximize economic returns to farmers who sell raw milk to the cooperative. Consequently, after desired capacity investments are fulfilled (also accounting for depreciated assets), surplus is paid to participating farmers as dividends or as a combination of dividends and higher milk prices. The capacity investment and dividend payments outflows are important to the performance of the cooperative. A maximum flexible cash decision rule (Appendix 2, Table A1, Eq. 35) assumes that a management objective is to maintain sufficient cash on hand to cover expected expenses for future months to prevent economic crises due to seasonal market uncertainties. 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. Costs and cost coverage time determine the desired balance (Appendix 2, Table A1, Eq. 36). Thus, the cooperative invests in capacity (Appendix 2, Table A1, Eq. 37) when there is a desired investment in capacity (Appendix 2, Table A1, Eq. 31) from the cheese cooperative productive capacity structure (Figure A5) and sufficient flexible cash on hand to make the investment.

We assume that the cooperative will always fulfill desired capacity investments before paying dividends to farmers. If excess flexible cash is available after fulfilling desired capacity investments, dividend payments can be made (Appendix 2, Table A1, Eq. 38 and 39). This is important primarily in the initial stages of the simulation as the cooperative expands capacity to meet consumer demand. Rather than pay quarterly, six-month, or annual dividends, the cooperative pays dividends on a continual basis after becoming solvent.

Cooperative Productive Capacity

The productive capacity module (Figure A5) represents maximum cooperative capacity to produce aged cheese. Thus, productive capacity serves as a proxy for cooperative physical assets. The cooperative initializes operations by making a small exogenous investment in productive capacity at the same time that aged cheese market development commences (2015). Following the initial investment, the capacity expansion structure (Appendix 2, Table A1, Eq. 30) acquires capacity endogenously when there is a desired capacity investment (Appendix 2, Table A1, Eq. 31) and sufficient flexible cash. Desired capacity investments respond to expected demand for aged cheese via the capacity deficit variable (Appendix 2, Table A1, Eq. 32). Capacity also depreciates over time through a first-order delay in the outflow from the capacity stock. Capacity utilization (Appendix 2, Table A1, Eq. 33) is a function of the ratio of expected orders to actual capacity in a reference multiplicative formulation (Appendix 4, Table A3). We assume that the cooperative will lower capacity utilization by decreasing milk purchases when cheese demand is low. Capacity utilization determines desired milk purchases (Appendix 2, Table A1, Eq. 34). Productive capacity depreciates over time and requires occasional reinvestment to maintain desired capacity.

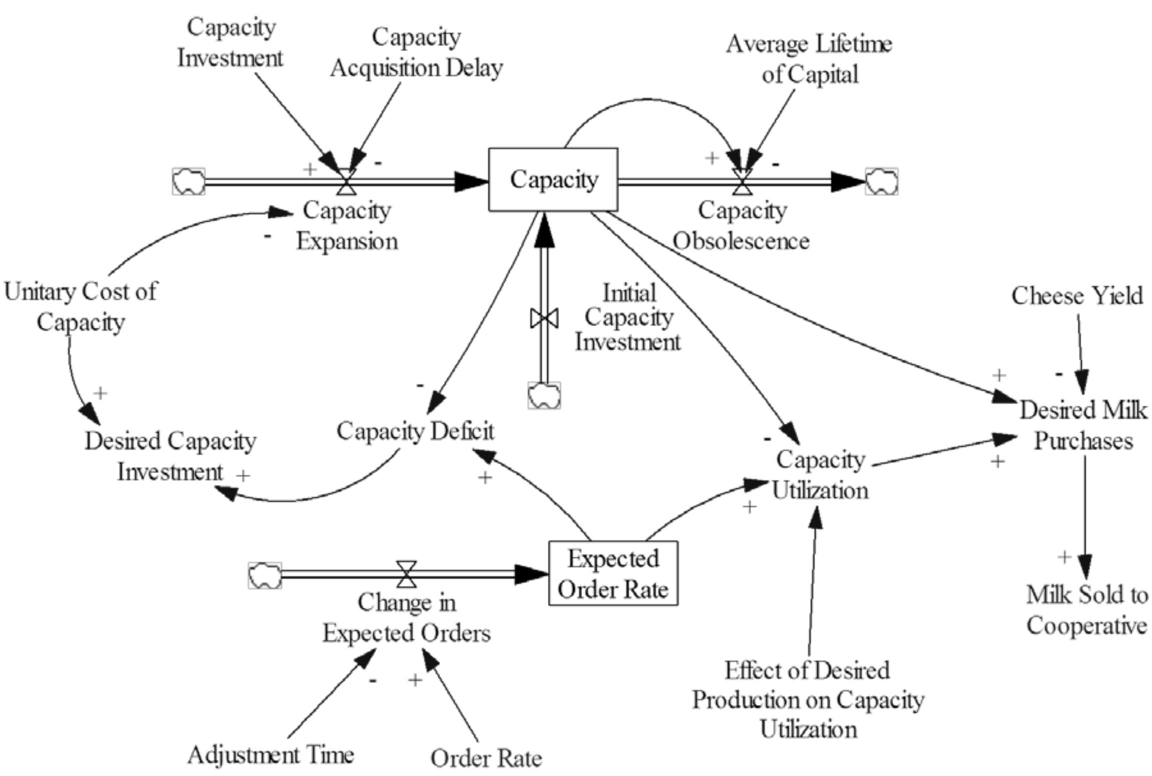

Figure A5. Productive capacity and utilization structure for the cheese cooperative

Cooperative Aged Cheese Manufacture

Purchased milk flows into the two-stock cheese manufacturing process (Figure A6) once the cooperative acquires productive capacity. Cheese yield from the processing of fluid milk

(Appendix 2, Table A1, Eq. 23) determines cheese production. This production rate transfers product into the aging cheese stock. The maturation delay affects the intermediate flow (maturation rate, Appendix 2, Table A1, Eq. 24) between the aging cheese stock and the inventory stock. It is a fixed delay of the cheese production rate. After maturation, product is transferred to the aged cheese inventory stock. It exits this stock through the order fulfillment rate (Appendix 2, Table A1, Eq. 25), which is a variation of the Fuzzy MIN function suggested by Sterman (2000). Consumer demand and available inventory determine orders filled. Order fulfillment represents cheese sales to consumers and is the sole source of income for the cooperative.

The quantity of cheese being produced, stored, and sold determines production costs, storage costs, and marketing costs, respectively. The unit cheese production costs (Appendix 2, Table A1, Eq. 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. Aged cheese price affects cheese revenues.

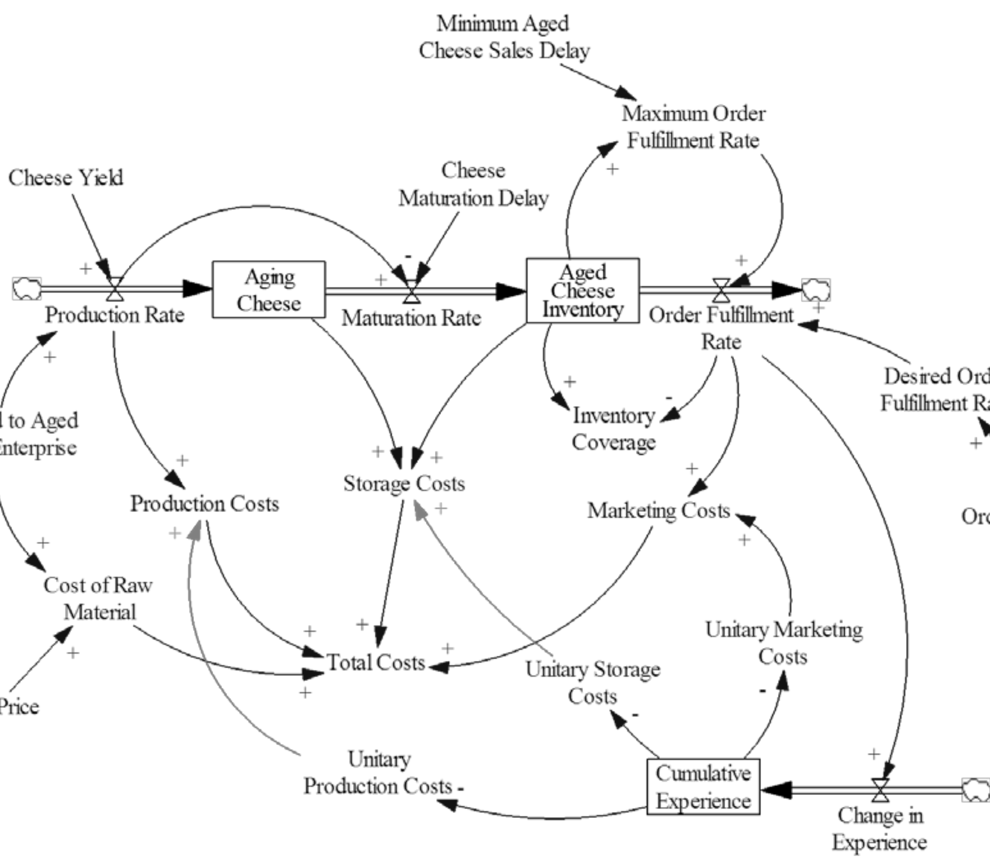

Figure A6. Simplified stock-flow structure of cooperative aged cheese production consisting of a two-stock aging chain

Market for Aged Cheese

The market for premium cheese module (Figure A7) represents the market in the larger nearby community of Xico, where buyers are hotels and restaurants serving the growing tourism industry. The market demand structure creates logistic growth in the number of actual buyers (e.g., restaurants, hotels, and private households). This directly affects product demand, desired cooperative productive capacity, and capacity utilization. The structure is adapted from the Bass Diffusion Model (Bass 1969), which is commonly used to estimate new product sales during the product growth phase (Sterman 2000).

The population of potential buyers (Appendix 2, Table A1, Eq. 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 fraction willing to adopt limits the number of potential buyers, which prevents the entire population from becoming potential buyers unless the price of aged cheese is extremely low. The adoption rate (Appendix 2, Table A1, Eq. 28) is the sole 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 (Appendix 2, Table A1, Eq. 29) depends on the interaction between actual buyers and potential buyers. The buyer interaction rate constrains adoption from word of mouth. The total population variable includes test structure to evaluate the effect of changes in market size on cooperative feasibility.

With the exception of unit costs and cheese price, the structure functions exogenously to the rest of the model to determine market demand. Limiting factors for market growth include the potential buyer population size, effectiveness of commercialization, and the buyer interaction rate.

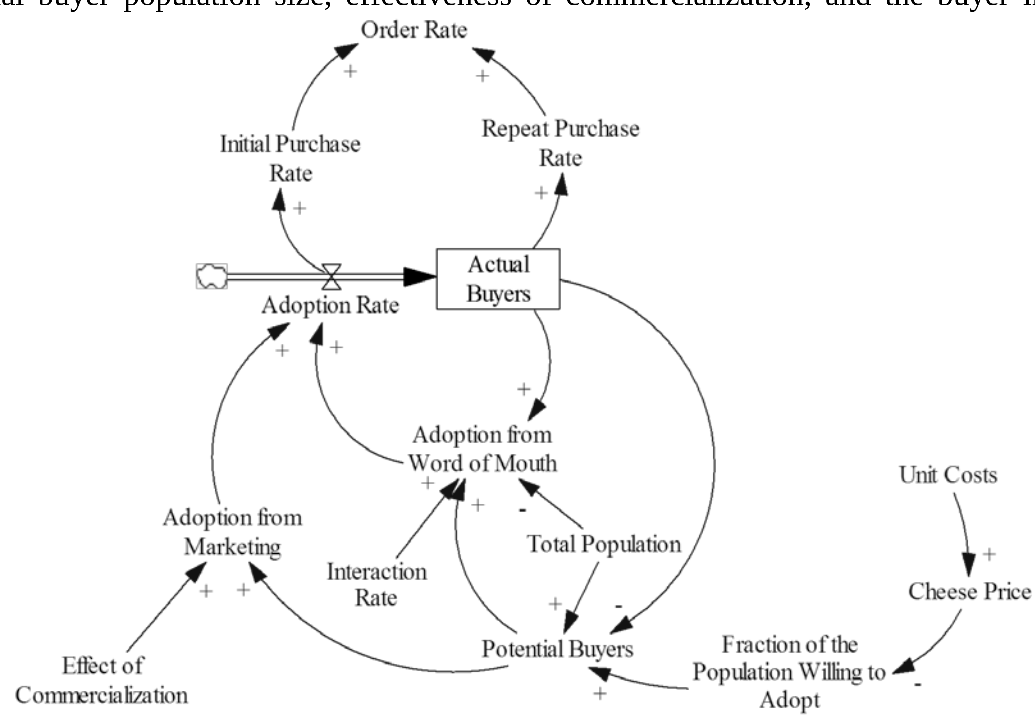

Figure A7. Simplified aged cheese market structure adapted from a typical two-stock market growth structure (Sterman 2000) to interface with unit costs and the price of aged cheese.

Net Income Expectations and Decisions for Goat Producers

The net income expectations and decisions module depicts monthly net cash operating income derived from young buck sales, culled goat sales, milk production, and dividend receipts. These variables represent farmer expectations (Appendix 2, Table A1, Eq. 40) about net incomes of goat production and milk production. Consequently, these variables influence producer decisions related to reinvestment of net cash operating income in different goat enterprises (e.g., goat purchases), the culling rate, and household milk consumption. Deducting forage production costs from the aforementioned sources of income derives the caprine income statement. The monthly net operating income from community caprine activities (Appendix 2, Table A1, Eq. 43) is derived from the income statement, and is considered the most relevant decision variable for smallholder farmers.

The profitability expectations module also contains oscillations in seasonal milk price. 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; Njarui et al. 2010). An exogenous sinusoidal function generates milk price oscillation between 4.5 pesos kg^{-1} during the dry season and 3.5 pesos kg^{-1} during the rainy season.

Other important indicators of goat enterprise performance include returns to labor (Appendix 2, Table A1, Eq. 41) and income over feed costs (Appendix 2, Table A1, Eq. 42). Although the endogenous structure ignores these variables, they are likely important to producer decision making. Family labor contributions are assumed gratis. Forage production costs also affect the monthly profitability of community caprine operations in this module.

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Appendix 2. Key Model Equations

Table A1. Model Equations (by module)

Eq. #	Equation	Units
	Community Goat Flock	
1	Fractional birth rate = (kids per parturition / birthing interval) * effect of forage availability on fractional birth rate(fraction of forage needs met)	$month^{-1}$
2	Desired does = adult does * effect of profitability on desired does (ZIDZ[2]((expected profitability-reference profitability), reference profitability))	does
3	Average time in flock = MAX[3] (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)	month
4	Culling rate = adult does/average time in flock	doe $month^{-1}$
5	Doe purchase rate = MAX ((MIN (purchases permitted based on available cash, (desired adult does – adult does) / desired adult does adjustment time)), 0)	doe $month^{-1}$
	Forage Resources	
6	Forage mass per caput = ZIDZ(forage mass, adult goats + weaned *cabritas*)	kg DM $goat^{-1}$
7	Fractional forage needs satisfied = forage mass per caput / reference forage mass per caput	dmnl[4]
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)	hectares $household^{-1}$
9	Fertilizer applied = reference fertilizer application * effect of perceived required forage needs met on fertilizer application(smooth fractional forage needs satisfied)	kg $hectare^{-1}$ $month^{-1}$
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)	kg DM $hectare^{-1}$ $month^{-1}$
11	Forage productivity = indicated forage productivity * (1 - seasonal rainfall switch) + seasonal productivity * seasonal rainfall switch	kg DM $hectare^{-1}$ $month^{-1}$
12	Seasonal forage productivity = indicated forage productivity * effect of seasonal rainfall on forage productivity	kg DM $hectare^{-1}$ $month^{-1}$
13	Effect of seasonal rainfall on productivity = (average monthly rainfall / overall average monthly rainfall) * indicated forage productivity	dmnl
14	Fertilizer costs = fertilizer applied * area in production * unit cost of fertilizer	pesos $month^{-1}$
15	Land costs = area in production * fixed monthly cost per hectare	pesos $month^{-1}$
16	Cost of labor to maintain and harvest forage = forage production * labor required to maintain and harvest forage * monthly rate for hired labor	pesos $month^{-1}$
17	Forage production costs = cost of labor to maintain and harvest forage + land costs + fertilizer costs	pesos $month^{-1}$
18	Cost to produce one kg forage DM = forage production costs / forage production	pesos $(kg\ DM)^{-1}$
19	Forage consumption = (adult goats + weaned *cabritas*) * base forage consumption per goat * (effect of forage allowance on consumption (ZIDZ(forage mass per caput, reference forage mass per caput)))	kg DM $month^{-1}$

[2] ZIDZ means "zero if divided by zero". When the denominator is 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)
[3] The MAX function returns the higher of two possible values (Ventana Systems, Inc. 2008). (e.g., MAX (4,7) = 7)
[4] Dimensionless

Eq. #	Equation	Units
	Milk Allocation	
20	Milk for income generation = MAX((milk production-milk consumed by kids-milk consumed by families) , 0)	kg day^{-1}
21	Milk sold to aged cheese enterprise = MIN(milk production for income generation, desired milk purchases)	kg month^{-1}
22	Milk sold in Xico = milk production for income generation – milk sold to aged cheese enterprise	kg month^{-1}
	Cooperative Aged Cheese Manufacture	
23	Production rate = cheese yield * milk sold to aged cheese cooperative	kg cheese month^{-1}
24	Maturation rate = DELAY FIXED(production rate, cheese maturation delay, production rate)	kg cheese month^{-1}
25	Order fulfillment rate = desired order fulfillment rate * order fulfillment table(ZIDZ(maximum order fulfillment rate, desired order fulfillment rate))	kg cheese month^{-1}
26	Unit costs = base unit costs *(cumulative experience / initial experience)$^{\text{strength of learning curve}}$	pesos (kg cheese)$^{-1}$
	Market for Aged Cheese	
27	Potential buyers = MAX(Fraction of the population willing to adopt * total buyer population – actual buyers, 0)	Buyers
28	Adoption rate = adoption from interaction + adoption from marketing	buyers month^{-1}
29	Adoption from word of mouth = ZIDZ((buyer interaction rate*proportion of adopters*actual buyers*potential buyers),total population)	buyers month^{-1}
	Cooperative Productive Capacity	
30	Capacity expansion = DELAY FIXED(capacity investment / unitary cost of capacity, capacity acquisition delay, 0)	kg cheese (month*month)$^{-1}$
31	Desired capacity investment = capacity deficit * unitary cost of capacity	pesos
32	Capacity deficit = MAX(0, expected order rate - capacity)	kg cheese month^{-1}
33	Capacity utilization = effect of desired production on capacity utilization (ZIDZ(expected order rate, capacity))	dmnl
34	Desired milk purchases = (capacity/cheese yield) * capacity utilization	kg month^{-1}
	Dairy Cooperative Management and Decisions	
35	Maximum flexible cash = MAX(0, MIN(cheese enterprise balance – minimum desired balance, cheese enterprise balance – desired balance))	pesos
36	Desired balance = costs * cost coverage time	pesos
37	Capacity investment = MIN(desired capacity investment / cheese enterprise balance adjustment time, MAX(0, maximum flexible cash / expense time))	pesos month^{-1}
38	Available dividends = MAX(0, (maximum flexible cash – expense time * capacity investment)/dividend expense time)	pesos month^{-1}
39	Dividend payments = available dividends * dividend activation switch	pesos month^{-1}
	Net Income Expectations and Decisions for Goat Producers	
40	Expected profitability = SMOOTH3(monthly profitability, smooth adjustment time)	pesos month^{-1}
41	Returns to labor = (monthly profitability of community caprine activities / number of families) / monthly hours worked per family	pesos hour^{-1}
42	Income over feed costs = milk sales income + culled goat sales income + *cabrito* sales income + dividend income – forage production costs	pesos month^{-1}
43	Monthly net cash operating income = monthly net income from milk and milk products + monthly net income from *cabrito* and culls – monthly forage production costs	pesos month^{-1}

References

Ventana Systems, Inc. 2008. Vensim® Version 5 Software Documentation.

Appendix 3. Model Parameter Values

Table A2. Parameter Summary Table (by module)

Parameter Name	Default Value	Units	Source and Comments
Control			
Time Step	0.0625	month	
Initial Time	0	month	
SavePer	1	month	
Initial Year	2013	year	Timebase
Years Per Month	0.0833	year $month^{-1}$	Timebase
Final Time	240	month	
Cooperative Productive Capacity			
Initial Cheese Cooperative Capacity	0	kg cheese $month^{-1}$	
Unit Cost of Capacity	50	(pesos*month) $(kg\ cheese)^{-1}$	
Capacity Utilization Switch	1	dmnl	1=on, 0=off
Initial Exogenous Capacity Investment	20	kg cheese $(month*month)^{-1}$	
Expected Orders Adjustment Time	1	month	
Initial Expected Order Rate	0	kg cheese $month^{-1}$	
Capacity Acquisition Time	1	month	
Average Capital Lifetime	240	month	
Cooperative Aged Cheese Manufacture			
Base Unit Storage Cost	5	pesos $(kg\ cheese*month)^{-1}$	
Base Unit Commercialization Cost	10	pesos $(kg\ cheese)^{-1}$	
Base Unit Production Cost	10	pesos $(kg\ cheese)^{-1}$	
Initial Experience	500	kg cheese	
Learning Curve	(0.02915)	dmnl	Equivalent to a 5% cheese making 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 Subsidy	0	dmnl	
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 $(kg\ milk)^{-1}$	

Parameter Name	Default Value	Units	Source and Comments
Cooperative Aged Cheese Manufacture-*Continued*			
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	
Dairy Cooperative Management and Decisions			
Minimum Desired Cash Balance	30,000	Pesos	
Dividend Switch	1	dmnl	1=on, 0=off
Initial Cooperative Investment	0	pesos month^{-1}	
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 cash on hand.
Capacity Expenditure Delay	1	month	
Dividend Expenditure Delay	4	month	
Initial Cooperative Cash Balance	30,000	pesos	
Forage			
Base Area in Production per Family	2	ha household^{-1}	INIFAP
Fixed Monthly Land Costs	10	pesos (ha*month)$^{-1}$	
Unit Fertilizer Costs	5	pesos kg^{-1}	Cristóbal Carballo, 5-8 pesos kg^{-1}for typical NPK mix
Reference Fertilizer Application	10	kg (ha*month)$^{-1}$	
Required Forage Consumption per Goat	60	kg DM (goat*month)$^{-1}$	INIFAP estimate
Seasonal Rainfall Switch	1	dmnl	1=on, 0=off

Parameter Name	Default Value	Units	Source and Comments
Forage-*Continued*			
Normal Monthly Rainfall Switch	1	dmnl	1=on, 0=off This switch allows historical monthly rainfall data (INIFAP 2006) 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 2006) can be activated in lieu of the normal monthly rainfall switch.
Monthly Labor Used Per Family	120	hours $(family*month)^{-1}$	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 DM^{-1}	Amount of labor required in months to harvest 1 kg forage. 1 laborer can harvest 1000 kg forage/month.
Months of Consumption	1	month	Used to calculate value of initial forage mass stock
Monthly Payment for Hired Labor	50	pesos $(laborer*month)^{-1}$	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 (2006)
Average Monthly Forage Productivity	250	kg DM $(ha*month)^{-1}$	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	
Community Goat Flock			
Base Average Time in Flock	84	month	INIFAP
Non-Feed Costs Per Goat	5	pesos $(goat*month)^{-1}$	INIFAP
Litter Size	2	dmnl	INIFAP

Parameter Name	Default Value	Units	Source and Comments
Community Goat Flock-*Continued*			
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^{-1}	INIFAP
Cabrito Price	300	pesos goat^{-1}	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^{-1}	INIFAP
Market for Aged Cheese			
Start of Commercialization	0	month	
Initial Actual Buyers	0	buyers	
Initial Purchases per Buyer	5	kg cheese buyer^{-1}	INIFAP
Average Consumption per Buyer	10	kg cheese (buyer*month)$^{-1}$	INIFAP
Demand Shock	0	kg cheese month^{-1}	
Demand Shock Duration	0	month	
Demand Shock Time	0	month	
Commercialization Effectiveness	0.005	month^{-1}	
Expansion to Other Markets	0	buyers month^{-1}	
Initial Population of Total Potential Buyers in Xico	30	buyers	INIFAP
Initial Aged Cheese Price	120	pesos (kg cheese)$^{-1}$	INIFAP
Price Shock	0	pesos (kg cheese)$^{-1}$	
Price Shock Duration	0	month	
Price Shock Time	0	month	
Buyer Proportion that Adopts Aged Cheese	0.5	dmnl	
Buyer Interaction Rate	0.25	month^{-1}	
Market Expansion Time	120	month	
Milk Allocation			
Daily *Cabrito* Milk Consumption	1	kg (*cabrito**day)$^{-1}$	INIFAP
Reference Household Milk Consumption	1	kg (household*day)$^{-1}$	INIFAP
Average Days per Month	30.42	days month^{-1}	Conversion factor

Parameter Name	Default Value	Units	Source and Comments
Milk Allocation-*Continued*			
Cooperative Switch	0	dmnl	1=on, 0=off
Reference Daily Milk Production per Goat	1.5	kg $(goat*day)^{-1}$	INIFAP, (Nagel et al. 2006)
Cooperative Start Time	24	month	The cooperative begins marketing and processing operations in 2015.
Net Income Expectations and Decisions for Goat Producers			
Amplitude	0.5	pesos kg^{-1}	INIFAP, amplitude of milk price oscillations in Xico market
Base Milk Price in Xico	4	pesos kg^{-1}	INIFAP
Milk and Traditional Cheese Production Costs	2	pesos kg^{-1}	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^{-1}	
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	
Smooth Monthly Profitability of Goats and *Cabritos* Adjustment Time	10	month	

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Appendix 4. Lookup Tables

Table A3. Lookup or Table Functions

Table Name	Function Values[5]	Units
Order Fulfillment Table	(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

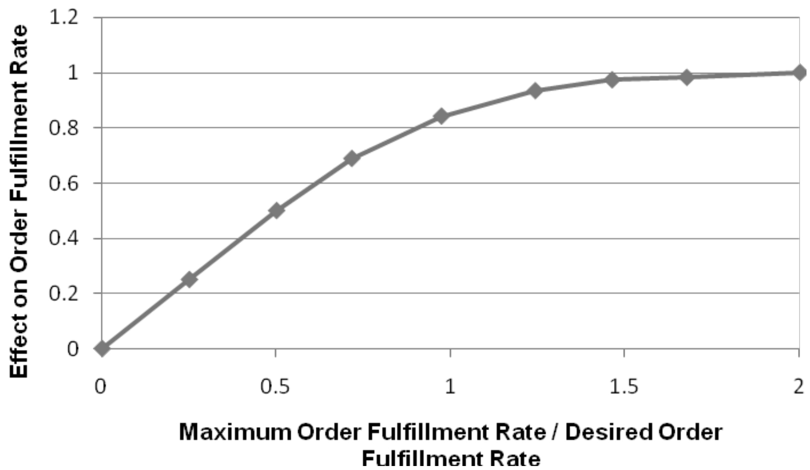
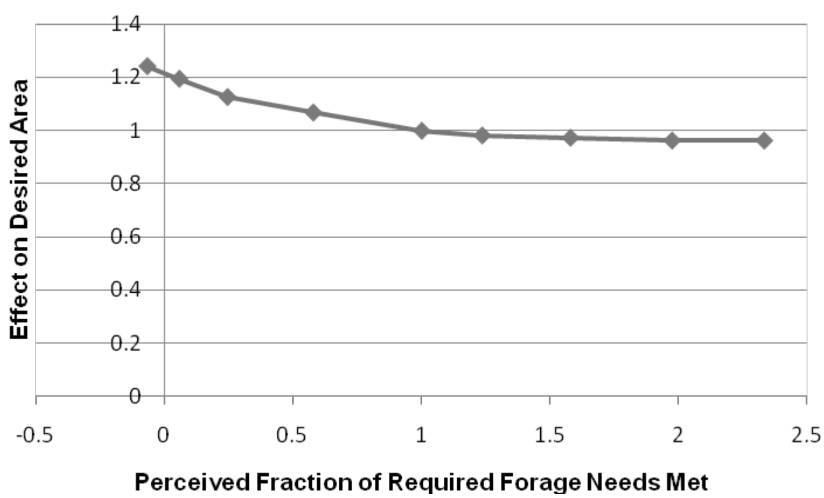


Table Name	Function Values	Units
Effect of Perceived Required Forage Needs Met on Desired Terrain in Production	(-0.0675229,1.24211), (0.0572477,1.19474), (0.244404,1.12632), (0.577737,1.06842), (1,1), (1.23547,0.982456), (1.57847,0.973684), (1.97382,0.963158), (2.33211,0.963158)	dmnl



[5] Lookup function values are (X, Y) pairs.

Table Name	Function Values[5]	Units
Effect of Forage Allowance on Animal Forage Consumption	(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

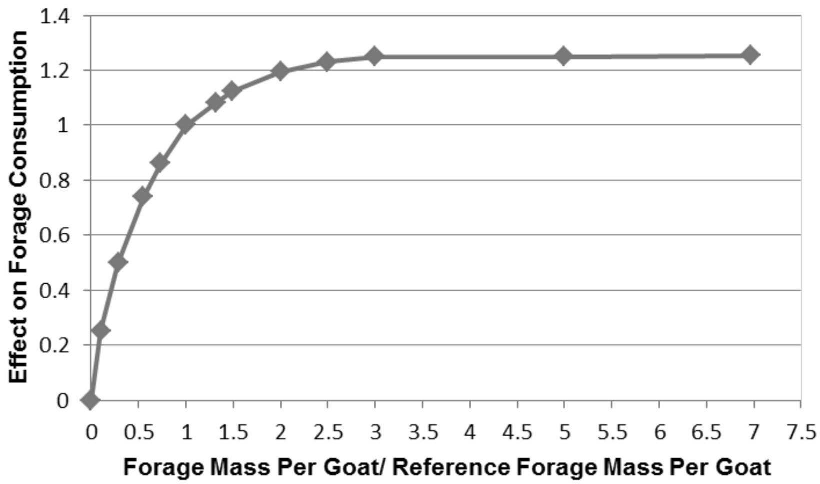


Table Name	Function Values[5]	Units
Effect of Desired Cheese Production / Production Capacity on Capacity Utilization	(0,0), (0.110092,0.298246), (0.238532,0.587719), (0.366972,0.754386), (0.599388,0.894737), (1,1), (2,1.1), (3,1.15)	dmnl

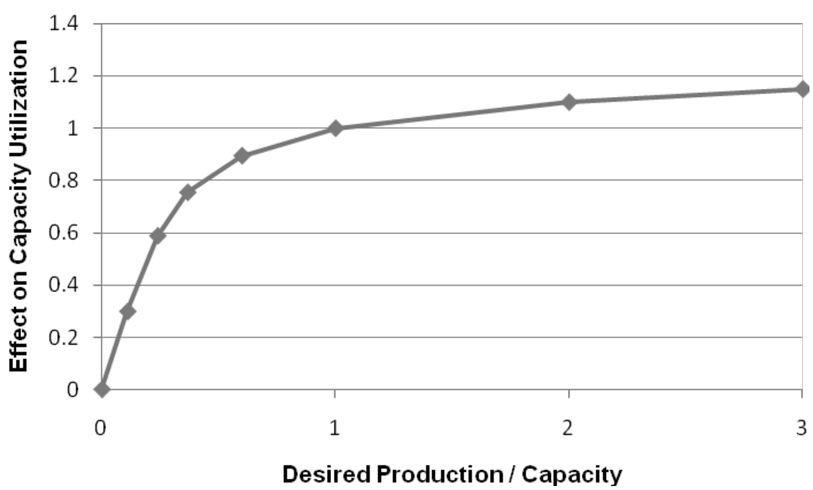
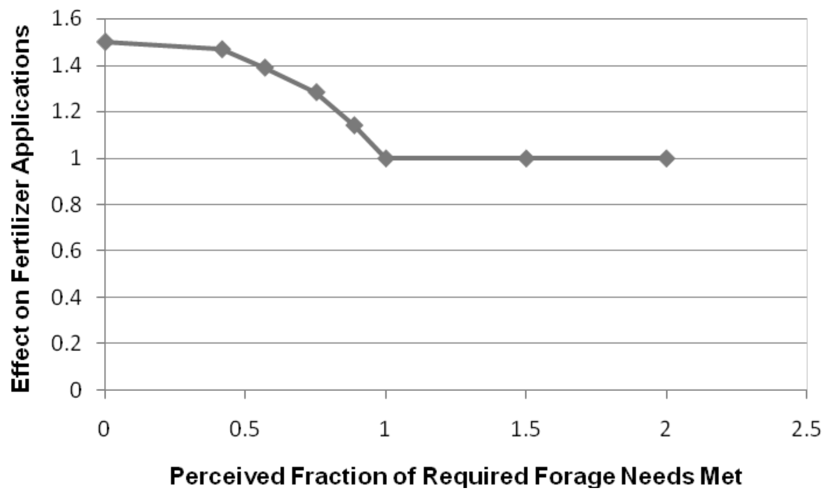


Table Name	Function Values[5]	Units
Effect of Perceived Required Forage Needs Met on Fertilizer Applications	(0,1.5), (0.415902,1.46842), (0.568807,1.38947), (0.752294,1.28421), (0.88685,1.14211), (1,1), (1.5,1), (2,1)	dmnl
Effect of Fertilizer on Productivity	(0,0.25),(0.5,0.65),(1,1),(1.5,1.25), (2,1.4),(3,1.6),(4,1.75)	dmnl



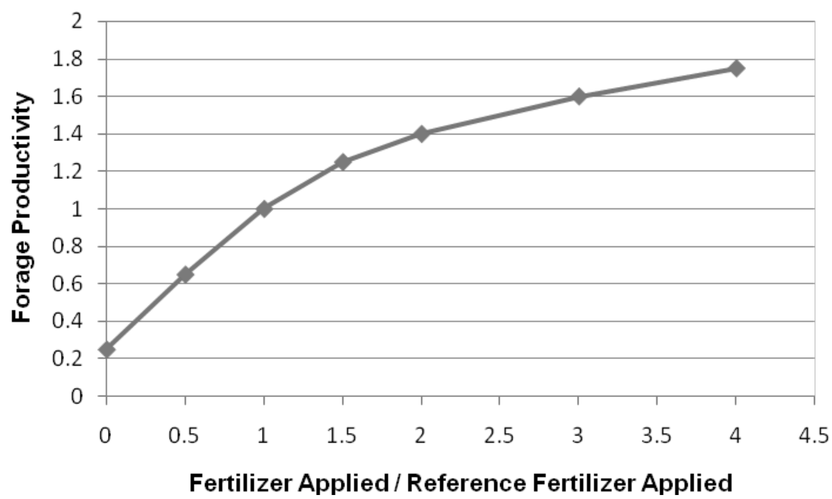


Table Name	Function Values[5]	Units
Effect of Forage Allowance on Adult Doe Fractional Death Rate	(0,10),(0.0611621,2.85088),(0.183486,1.84211),(0.550459,1.27193),(1,1),(1.40673,0.701754),(1.98777, 0.350877),(4,0.1)	dmnl

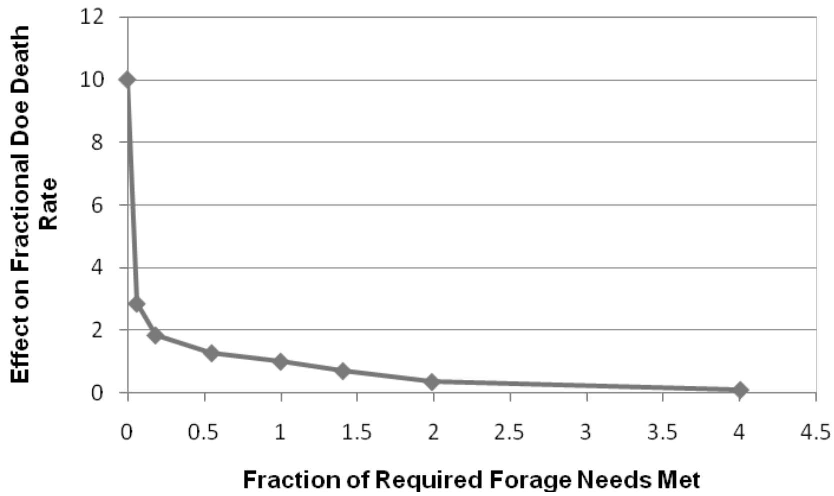


Table Name	Function Values	Units
Effect of Forage Allowance on Fractional Birth Rate	(0,0), (0.324159,0), (0.501529,0), (0.556575,0.245614), (0.685015,0.54386), (0.831804,0.833333), (1,1), (1.43119,1.14035), (2,1.25)	dmnl

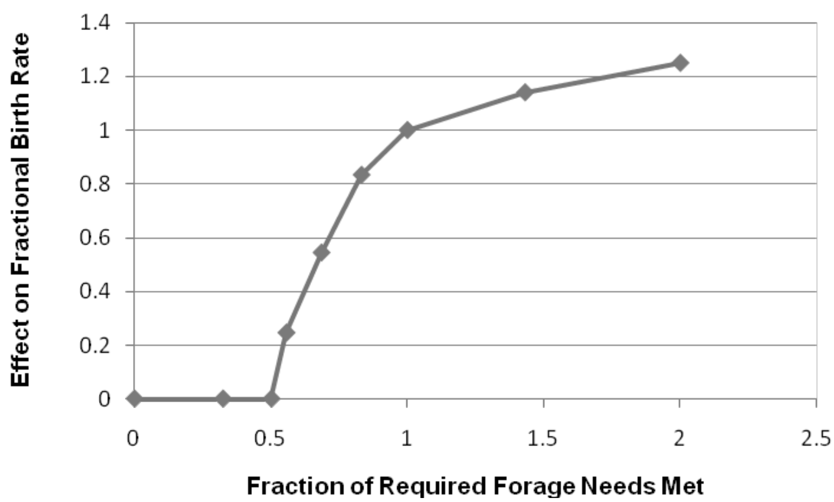
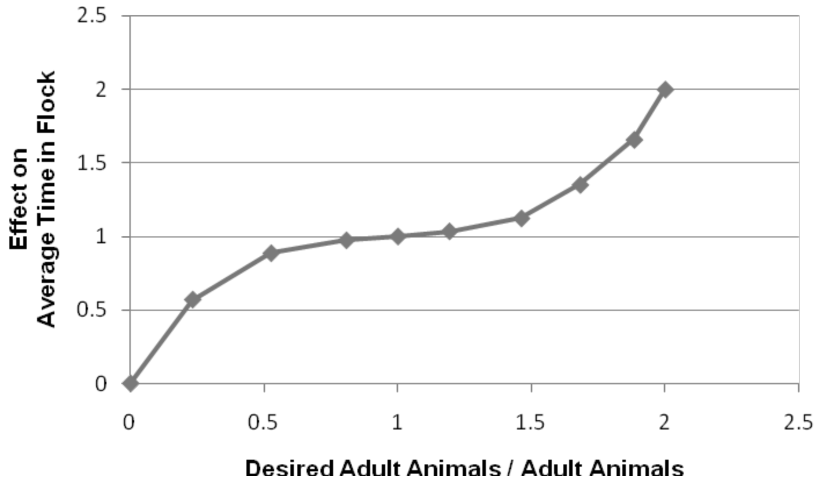


Table Name	Function Values[5]	Units
Effect of Desired Adult Animals/Adult Animals on Average Time in Flock	(0,0), (0.232416,0.570175), (0.525994,0.885965), (0.807339,0.973684), (1,1), (1.19266,1.03509), (1.46177,1.12281), (1.68196,1.35088), (1.88379,1.6578 9), (2,2)	dmnl



Effect of Expected Net Income on Desired Adult Goats	(-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

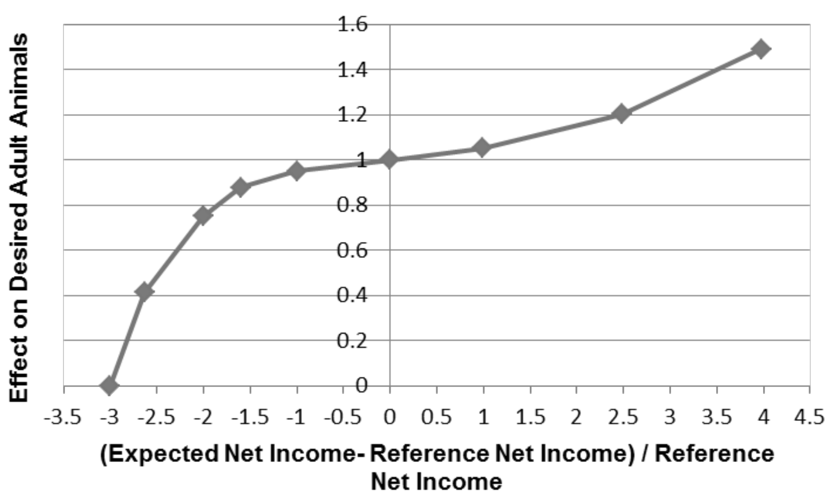


Table Name	Function Values[5]	Units
Effect of Aged Cheese Costs on Aged Cheese Price	(0,0), (1,1), (2,2)	dmnl

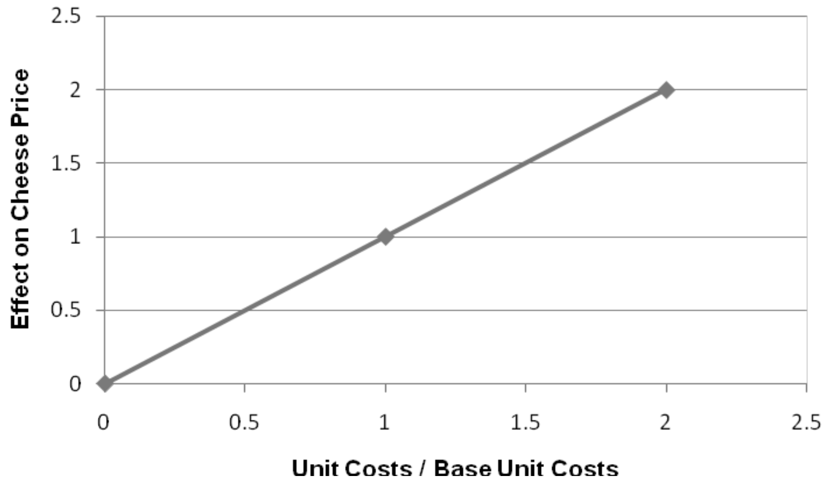


Table Name	Function Values[5]	Units
Effect of Forage Allowance on Milk Production	(0,0), (0.6,0), (0.611621,0.412281), (0.691131,0.719298), (0.831804,0.894737), (1,1), (2,1.5)	dmnl

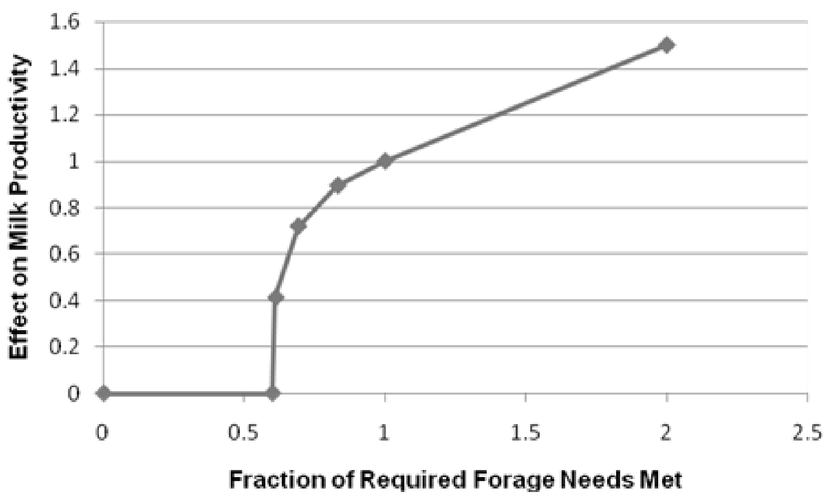
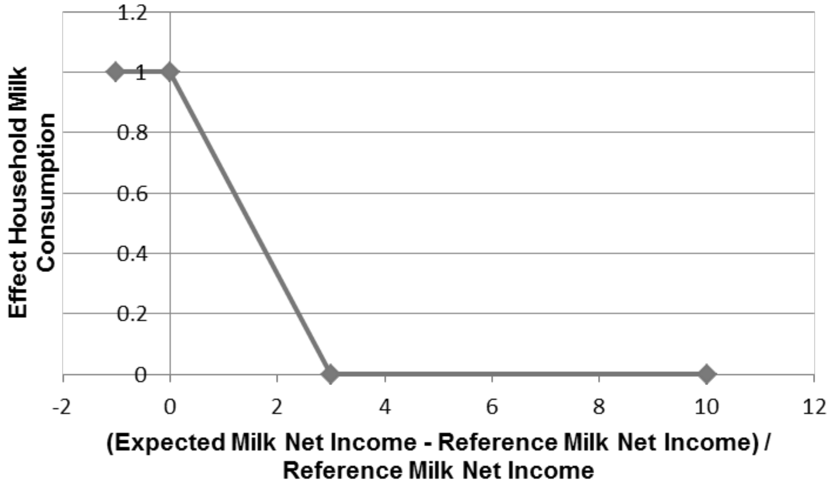


Table Name	Function Values[5]	Units
Effect of Expected Net Income of Milk on Household Milk Consumption	(-1,1),(0,1),(3,0),(10,0)	dmnl



Appendix 5. Seasonal Weather Patterns from 1961 to 2002

Table A4. Recorded Mean Monthly Weather Data at Teocelo, Veracruz Weather Station (INIFAP 2006)

	Precipitation (mm)		**Maximum Daily Temperature**		**Minimum Daily Temperature**		**Daily Photoperiod**
Month	Mean (mm)	CV (%)	Mean (ºC)	CV (%)	Mean (ºC)	CV (%)	Mean (hr)
January	58.66	77.3	21.34	10.9	11.36	13.2	11.0
February	56.10	64.9	22.45	10.7	12.10	11.7	11.4
March	79.66	120.4	25.08	7.7	13.83	9.1	11.9
April	78.24	61.5	27.37	6.8	15.58	6.0	12.5
May	146.56	63.4	28.14	7.1	16.63	6.3	12.9
June	351.69	41.1	27.28	6.9	16.69	5.7	13.2
July	297.20	40.7	26.59	5.5	15.76	4.3	13.1
August	283.46	46.8	26.70	4.9	15.79	3.9	12.7
September	376.96	34.4	26.07	5.0	15.99	4.3	12.2
October	193.91	46.9	24.85	6.1	14.91	5.3	11.6
November	104.51	67.9	23.63	8.1	13.62	10.0	11.1
December	67.51	49.5	21.73	7.9	12.27	9.7	10.8
Annual	**2094.45**	14.9	25.11	4.3	14.55	3.7	12.0

Appendix 6. Model Evaluation

Model evaluation was completed using the model testing procedure outlined by Sterman (2000). The model was tested with and without seasonal rainfall patterns imposed. Therefore, some sensitivity results may not reflect the same results that would be achieved when seasonal rainfall patterns are present.

Boundary Adequacy

The model boundary is adequate and consistent with the purpose of the model. Most key components of the model are endogenous. The exclusion of forage quality from the model is one notable exception. 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 by the cooperative. However, the time horizon can be lengthened as a test input to assess even longer-term impacts of value-added goat's milk production and shocks.

Structure Assessment

The model does not violate basic physical laws. The model structure does not include forage quality. A seasonal forage production proxy is based on rainfall data to test variability in forage production. Partial goats are possible in the model. This permits more continuous behavior in lieu of modeling the biological processes as static events.

Dimensional Consistency

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

Parameter Sensitivity Testing

Group model building sessions with INIFAP determined most parameter estimates. These estimates were derived from participants' expert knowledge of the system, which included the perspectives of many relevant stakeholder groups. Additional sources included unpublished documents from the INIFAP – Sitio Experimental Teocelo micro-watershed development project, personal correspondence with the INIFAP micro-watershed development team outside of group model building sessions, and other reports (e.g., Instituto Nacional de Ecología 2002). Parameter values are close to actual real world values and have real world meaning. However, a varying degree of uncertainty exists for parameters such as delays, adjustment times, and those associated with the production of aged cheese by a dairy cooperative and with the aged cheese market. Thus, sensitivity testing was completed for all parameters.

We undertook parameter sensitivity testing to evaluate the probability that operation of the cooperative would be economically infeasible (i.e., that it would fail financially or producer incomes would fall below historical levels). Sensitivity tests were completed for all model parameters using Latin Hypercube sampling with 100 simulations. Policy-sensitive parameters included cheese yield, cheese price, milk production, milk and cheese production costs, milk consumption levels, fluid milk price, and values affecting flock composition. Combined with production and market shocks, the limited number of policy-sensitive parameters suggests that the basic cooperative concept is potentially financially feasible and likely to increase Micoxtla family net incomes.

Extreme Conditions

Numerous extreme conditions tests were conducted, and model performance was realistic 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 an unreasonably high number.

Time Step Assessment

The current time step of 0.0625 month is adequate. The time step should be one-fourth to one-tenth as large as the smallest time constant in the model (Sterman 2000). The smallest time constant in the model is 0.25 month. 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 approximates the hypothesized behavior of the system under normal and extreme conditions. It reproduces the assumed reference mode behavior given current model structure. No behavioral comparisons are made to actual data.

Surprise Behavior

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

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