Dynamic Analysis of Policy Options for Mexico's Sheep Sector[1]

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Abstract

Global demand for livestock products is expected to increase rapidly during the next two decades, and the global value of livestock products will exceed that of crops by 2020. This so-called "Livestock Revolution" (Delgado et al., 1999) will challenge policy makers in many countries to re-examine their objectives and formulate appropriate policies to achieve them. Most analyses of growing livestock product demand have used global partial equilibrium market models to explore broader implications, such as impacts on grain markets (e.g., Bruinsma et al., 2003; Rosegrant et al., 2005; OECD, 2006). Country- and regional-level dynamic models that focus on livestock can complement these global analyses by assessing a more specific set of market and technology policy options. An example of the policy challenges in responding to the Livestock Revolution can be observed in Mexico. The demand for sheep meat in the populous central region around Mexico City has grown rapidly in recent years, prompting federal and state governments in sheep-producing regions to provide a variety of investment and feed subsidies as "regional development" strategies. To assess the impacts of these policy options in the context of ongoing demand growth, a dynamic model of Mexico's sheep sector with regional and producer group disaggregation is developed that incorporates interactions between herd dynamics, feed dynamics, market inventories of sheep meat and prices for sheep meat and animals. The model is used to assess the outcomes for commercial and *tras patio* (backyard, small-scale) Mexican sheep producers and sheep meat consumers of three growth assumptions and two intervention alternatives: a variable cost subsidy provided to commercial sheep producers or the implementation of a stylized health intervention that reduces the mortality rate

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of young sheep. Model simulations indicate that the dynamics of growth dominate the policy responses; the principal beneficiaries of producer subsidy and animal health interventions are Mexican sheep meat consumers, who are often high-income urban residents. Commercial sheep producers will experience increases in cumulative net margin, but *tras patio* producers will be made worse off than they would have been in the absence of interventions. The Mexican sheep system thus exhibits two characteristics of dynamically complex systems: unintended consequences (e.g., reduced cumulative net margins for all sheep producers in some cases as a result of policy) and policy resistance—the ability of the endogenous response of the system to various incentives to limit the ability of policy to achieve specified objectives. Although the principal results of this modeling effort are specific to the Mexican sheep case, there are broader implications related to modeling the evolution of agriculture-based livelihood systems, the "complex systems" approach to analysis of agricultural systems and the usefulness of interdisciplinary research collaboration.

Dynamic Modeling of Policy Options for Mexico's Sheep Sector

Introduction

Global demand for livestock products is expected to increase rapidly during the next two decades, and the global value livestock products will exceed that of crops by 2020. This so-called "Livestock Revolution" (Delgado et al., 1999) will challenge policy makers in many countries to re-examine their objectives and formulate appropriate policies to achieve them. Most analyses of growing livestock product demand have used global partial equilibrium market models to explore broader implications, such as impacts on grain markets (e.g., Bruinsma et al., 2003; Rosegrant et al., 2005; OECD, 2006). Country- and regional-level dynamic models that focus on livestock can complement these global analyses by assessing a more specific set of market and technology policy options. Of particular concern is how market transformations will influence the ability of smallholder livestock producers to participate in, and benefit from, rapid demand growth. Tedeschi et al. (2011), Nicholson et al. (2011) and Parsons et al. (2011) argued that system dynamics (SD) models of livestock systems can be useful to policy makers in a variety of ways as the livestock revolution progresses.

An example of the policy challenges in responding to the Livestock Revolution can be observed in Mexico. The demand for sheep meat in the populous central region around Mexico City has grown more than 6% annually in recent years (FAO, 2006). Already there have been structural changes in the agriculture of some regions of Mexico due to this growth. The Yucatán region illustrates many of these changes. Parsons et al. (2006) reported that sheep production had become a much more important source of household cash income in Yucatán state between 1989 and 2004. This rapid growth has prompted federal and state governments in sheep-producing regions to provide a variety of investment and feed subsidies as "regional development" strategies. In response to the perceived opportunity for sheep production to contribute to the region's economic growth, the state government of Yucatán has granted subsidies to sheep producers, particularly in the form of subsidized loans, cost-sharing grants or input cost subsidies. This financial assistance has almost always been directed to larger-scale, commercial producers, and has both lowered the investment cost for entry into larger-scale sheep production and reduced operating costs. In part, this financial assistance derives from a philosophical legacy in Mexico of the desirability of self-sufficiency in agricultural production. Although roughly half of sheep meat consumed in Mexico is imported (mostly from New Zealand), policy makers in Mexico see an opportunity to capitalize on consumer preferences for fresh rather than frozen sheep meat,[2] increasing earnings in the agricultural sector and reducing import dependency with a single set of policies.

At the same time, researchers at a number of Gulf region universities and the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP; Mexico's national agricultural research service, similar to the USDA's Agricultural Research Service) have been working on technologies and practices to improve the productivity of the systems (e.g., reduce mortality, increase both the production and quality of feed for livestock). Given the paucity of agricultural economists working for INIFAP, *ex ante* impact assessments are infrequently conducted for technologies under development, either at the level of the individual production unit or at the market level. Thus, little is known about the potential market impacts of successful development and implementation of these technologies. Moreover, relatively little is known to date about the characteristics of demand growth in Mexico City, although a recent study examined marketing channels for sheep meat (Fell, 2005). Most policy makers in state governments in Mexico seem to be operating under the assumption that the current rate of demand growth will continue indefinitely, and that sheep meat prices will remain at levels profitable for producers regardless of the actions of policy makers or producers.

In a more general sense, in agriculture and international development contexts there are often significant delays in the development and implementation of technologies and policies, and agriculture-based livelihood systems are in constant and sometimes rapid evolution. In order to make technologies and policies better match the future state of these systems, it is necessary to better understand the likely evolution of agricultural systems. The goal of these efforts should be to improve understanding about which technologies and policies will be relevant for the state of future systems so that research can begin on them now. In essence, researchers, policy makers and donors need an improved understanding of general behavioral tendencies for target systems five to ten years hence. Although this idea is widely accepted, assessment of systems evolution appears to have been addressed infrequently and largely in an *ad hoc* manner in international

[2] The majority of mutton consumed in Mexico City is as what is called "barbacoa." This is grilled sheep meat that is typically consumed on Sunday afternoons, and for which freshly slaughtered young sheep are the preferred source.

agricultural research. Nicholson (2007) noted that analyses of systems evolution will be more useful if they allow simultaneous treatment of both underlying drivers of the dynamics of agricultural livelihood systems and the impacts of technological and policy options. He also proposed that a set of integrated case studies of agricultural systems evolution using alternative modeling approaches be undertaken to improve our understanding of both systems evolution and the strength and limitations of various modeling approaches.

Thus, the objectives of this paper are two-fold. The first objective is to assess the likely dynamic impacts of technological change and state government support policies on the profitability of Yucatecan sheep production for different types of producers. One technology (a stylized health intervention that reduces animal mortality) and one policy option (stylized variable cost subsidies) are assessed under three different assumptions about future demand growth. The second objective is to provide one case study of how analyses of systems evolution can incorporate specific policy and technology options. To achieve these objectives, a system dynamics model of sheep markets in Mexico is developed and parameterized.

Model Specification

Sterman (2000) and Costanza et al. (1993) argue that most coupled human-natural systems have the characteristic of dynamic complexity, that is, they can demonstrate unanticipated changes in behavioral modes as a result of the interaction of factors endogenous to the system (even in the absence of significant external shocks). As a result, short-term and long-term effects of interventions may differ, and the outcomes of policy interventions are often offset to a substantial degree or result in the converse of what was intended. Batty and Torrens (2005) carry this discussion further, suggesting that "Complex systems generate a dynamic which enables their elements to transform in ways that are surprising, through adaptation, mutation, transformation and so on…the hallmark of this kind of complexity is novelty and surprise which cannot be anticipated through any prior characterization. All that can be said is that such systems have the potential for generating new behaviors."

To address the potential for dynamically complex behavior in Mexico's sheep industry, an integrated dynamic model of sheep markets, sheep flock dynamics and feed resources is appropriate. This model represents a stock-flow-feedback structure that captures the potential for nonlinear (or counterintuitive) responses to current policy instruments. The model represents sheep and sheep meat markets in Mexico, but also includes trade linkages because of the importance of imported sheep meat in Mexican consumption. The production sector is represented by two different regions (Yucatán and Other[3]), each with two different types of producers. Parsons et al. (2006) categorized producers in Yucatán state as either commercial or *tras patio*. Commercial producers tend to be larger scale, have better access to capital, have good market access and are often owned by individuals for whom agriculture is not the principal economic activity. *Tras patio*, or backyard, producers are smaller scale, often have a limited investment other than animals, have poorer market access and are owned by individuals who earn a significant portion of household cash income from agriculture. The differences in producer characteristics are assumed to influence the costs of production and prices received for live animals. Demand is assumed to exist at a single central market based in Mexico City. Inventories of sheep meat are assumed to influence the price of sheep meat, which in turn influences both sales (quantity demanded) and sheep meat imports. An overview of the various model sectors and assumptions follows, and a diagrammatic representation of the model (as a stock-flow structure) are shown in Figure 1. A more detailed and mathematical representation of the model structure is in the Appendix.

Animal Numbers

This part of model structure is an adaptation of that in the Meadows (1970) model of the US hog sector. The model specifies two types of animals: breeding sheep (BS) and young stock (YS). BS produce YS with delays for gestation and maturation, and with mortality losses. It is assumed that YS are either sold when "mature" or enter into the BS flock. The maximum rate at which YS can enter the BS flock is one-half of the maturation rate to account for only females entering the BS flock. The reproduction rate of the BS flock depends on the lambing interval, the lambs per lambing, and the fraction of mortality. The model assumes that the lambing

[3] Yucatán produces a small proportion of Mexico's sheep meat; less than 2% of the national sheep flock is found in Yucatán state. However, Yucatán is of interest given the policies implemented in response to the growth in demand for sheep meat.

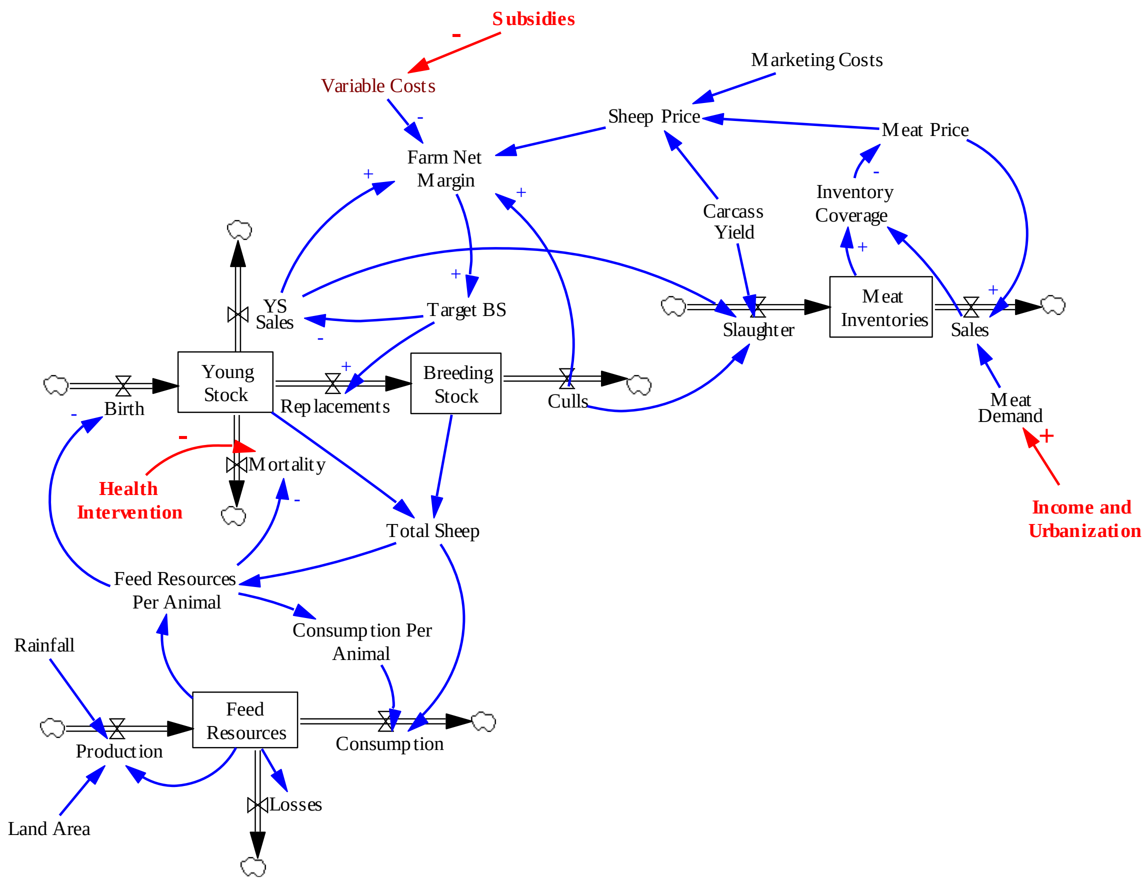

Figure 1. Simplified Stock-Flow Structure of the Dynamic Disequilibrium Model

interval and mortality depend on relative feed availability (i.e., nutrients consumed), and allows for of technological interventions to decrease YS mortality.

The number of BS depends on two flows: entrants into the BS flock (the replacement rate) and culls of BS. The rate of entrants depends on a replacement rate and an adjustment for differences between the current BS and a desired number of BS. Mean time in BS is increased if the number of desired BS is greater than the current BS. Maintenance or expansion of the BS takes precedence over YS sales. Of those maturing, all males are sold, but only those females not desired for the BS are sold.

The key behavioral assumption for sheep producers relates to the determination of the desired level of BS, which in turn determines desired replacement animals, adjustments to the current level of BS, the culling rate and the number of YS sold. The desired BS is based on an anchoring and adjustment heuristic that Sterman (2000) argues is commonly used in capacity-related decisions. The desired BS depends on the current BS and the expected long-term net margin of sheep production relative to a reference value of net margin.

Feed Resources

The model includes a single aggregated "local" feed resource, which assumes that most of the feed resources used in sheep production are forage or browse and are available locally (i.e., not traded among regions or producers). This is not quite accurate, because commercial sheep producers in particular buy feeds, but it may be adequate for a first model because the majority of feed resources available are those grazed by the animals. The quantity of feed available is increased by feed production and decreased by feed consumption. Total feed production depends on the land area, feed production per land area and relative (regional) rainfall. Feed consumption depends on the number of animals, a base level of per-month feed consumption and the availability of feed per animal, with consumption increasing nonlinearly with increases in feed availability. Seasonal differences in feed quality and interactions between quality and quantity are ignored. The availability of feed per animal is used to modify the reproductive performance of the sheep flock, with monotonically decreasing functions specified for both the time required for YS to mature and the lambing interval.

Sheep Market

A single aggregated sheep market (i.e., in Mexico City) consists of an inventory of sheep meat (i.e., distinct from sheep numbers), which is assumed to influence price-setting for sheep meat and therefore sheep meat sales. Although income and population growth will be the key drivers of sheep meat demand, the model does not include these directly. Rather, it includes structure to create exogenous growth in demand to test the impact of various demand growth patterns on the sheep production and marketing system. The assumed own-price demand elasticity is -0.5 based on estimates for other livestock products in Mexico[4] (Stout and Abler, 2004). The sheep meat price is assumed to translate into a producer sheep price by subtracting the per kg meat marketing costs and multiplying by the number of kg meat per animal (the carcass yield, which is set equal to 55% of the mature BS weight of 40 kg and 65% of the mean YS weight of 25 kg).

[4] Stout and Abler (2004) report own-price elasticities for beef and veal (-0.334), pork (-0.550) and poultry (-0.620).

Meat marketing costs are assumed to vary by region and producer type (to reflect the potential relative disadvantage to Yucatecan producers and smaller *tras patio* producers). This implies that the net price received by producers, and the aggregated net margin, will differ by region and producer type. Producer revenues are calculated as animal sales time animal prices. Producer costs include fixed costs (close to 40% of total costs based on observations made during field visits in 2004 and 2005) and variable costs (just over 60% of total costs). The latter are based on costs per BS, assuming that the majority of variable costs are for the breeding flock.

Technology Adoption and Subsidy Policies

As noted above, the model includes two regions (Yucatán and "Other") and two (aggregated) types of producers (commercial and *tras patio*). Commercial producers are assumed to receive all state government subsidies and to be the only adopters of new technologies. The proportion of commercial producers that use a technology is time-dependent and is assumed to demonstrate sigmoidal growth to full adoption over three years.[5] The adoption of a stylized health intervention by commercial producers is assumed to reduce the mortality of YS, for which mortality rates average about 20% per year. An investment subsidy percentage variable allows the variable costs of sheep production to be reduced, to simulate the effects of cost subsidies provided by state governments. Based on the observation that in practice a preponderance of the cost subsidies are received by commercial producers, we assume that only commercial producers are eligible for the subsidy payments. In contrast to the technological intervention, for which a diffusion and adoption process is required and which only a proportion of the commercial producers choose to use, the subsidy payments program is assumed to be implementable over a short time horizon and all eligible (that is, commercial) producers will receive payments. For clarity, we do not report the results for both policy options implemented simultaneously.

Mathematical Formulation and Solution

Mathematically, the model is formulated in Vensim® (a detailed discussion of the structure is included in the Appendix). The model includes four key state (stock) variables (BS, YS, feed resources and sheep meat inventories). The inclusion of inventories that mediate between

[5] Thus, this assumes that the technology would be regarded as highly desirable for producers. Sensitivity analyses were used to assess the importance of this assumption and the outcomes do not change in a qualitative sense.

current sheep meat production and current sales implies the possibility for dynamic disequilibrium in Mexican sheep meat markets. The model time unit of observation is one month, and the calculation time step is 0.125 months.[6] The model is initialized in dynamic equilibrium for time t=0 representing data from 2005,[7] and technology or policy changes are assumed to be initiated at time t=12 months. The model is simulated for a total of 120 months using the Euler method of numerical integration. The model has been evaluated following the procedures outlined in Sterman (2000) for dynamic simulation models, and various sensitivity and extreme conditions tests have been conducted but are not reported herein.

Policy Options Analyzed

Nine alternative scenarios are analyzed with the dynamic model (Table 1). These scenarios are 1) a base case that assumes no changes in YS mortality over time due to technology adoption and no variable cost subsidy, 2) a scenario in which YS mortality is reduced from 20% to 10% per year due to a stylized health intervention (assumed to be developed by Mexican university and INIFAP researchers)[8] for commercial producers in both regions, and 3) a scenario in which governments provide variable cost subsidies that lower by 20% the unit costs of sheep production for commercial producers in both regions. Each of these scenarios is assessed under three different demand growth scenarios: No growth (which serves as a dynamic equilibrium baseline in the absence of technological change or subsidies), growth of 6% per year throughout the simulation and 6% growth over four years, slowing to 2.5% growth over the remaining years of the simulation. This latter scenario is designed to test the importance of the assumption on the part of state-level policy makers concerning continuous rapid growth in the Mexico City market. The key outcomes of interest to policy makers from these simulations are sheep meat prices, net margins for each type of producer in both regions, total consumer expenditures on sheep meat and government expenditures on variable cost subsidies.

[6] Alternative values of the time step were used to evaluate the degree of integration error. The value of 0.125 was determined to be adequate as a compromise between computational requirements and the likely degree of computational error due to the assumption of dS/dt is constant for the interval Δt, as assumed for Euler integration.
[7] Principal data sources include FAO (2006), Parsons et al. (2006), field visits in 2004 and 2005 and G. Ríos Arjona (personal communication).
[8] In most *ex ante* impact assessments, the costs of research investments would be included. Due to the stylized nature of the intervention modeled, no research or implementation costs are included, and it is assumed that the "technology" involves changes in management practices for which no additional costs are incurred by producers.

Table 1 Policy Options Analyzed

Technology or Policy Alternative	Growth Assumption		
	No Growth	Constant Growth	Slowing Growth
Baseline (No Change)	0% growth; No changes in technology or policy	6% annual growth; No changes in technology or policy	6% growth for 4 years, 2.5% growth subsequently; No changes in technology or policy
Subsidy	0% growth; 20% variable cost subsidy for commercial producers	6% annual growth; 20% variable cost subsidy for commercial producers	6% growth for 4 years, 2.5% growth subsequently; 20% variable cost subsidy for commercial producers
Reduced Mortality	0% growth; Reduction of YS mortality from 20% to 10%	6% annual growth; Reduction of YS mortality from 20% to 10%	6% growth for 4 years, 2.5% growth subsequently; Reduction of YS mortality from 20% to 10%

Results

The results are presented using two approaches. First, a graphical representation of key variables over the model time horizon is provided for selected variables. The graphical approach facilitates discussion of the dynamic effects of the interventions because their short-term and long-term effects often differ. Second, as a means of summarizing the overall policy or technology effects over a ten-year period, tabular summaries of relevant variables are reported and compared to a baseline dynamic equilibrium without growth. Although the scenarios with no demand growth are not realistic, they provide insights that are relevant for latter consideration of the two scenarios with growth. As noted above, the key variables of likely interest to policy makers and agricultural researchers are the sheep meat price, net margins for different types of sheep producers in the two regions, and government expenditures on variable cost subsidies.

No Growth Scenarios

The effects of the subsidy policy and the intervention to reduce mortality have differing initial effects on Mexican sheep markets. The subsidy reduces commercial producers' costs of production, increasing net margin. As a result of this immediate increase in profitability, commercial producers seek to expand sheep numbers (that is, the desired number of BS increases). In the short-term, this results in an inverse supply response, because a larger number of female YS are retained for inclusion in the breeding flock (Figure 2). The sheep meat price increases for a period of about 18 months as commercial producers adjust their BS holdings, but as the gap between desired and current BS holdings is closed and more YS are being produced, prices fall below the level observed in the dynamic equilibrium simulation (Figure 3). The subsidy policy also results in oscillatory behavior of prices over a period of about seven years. Initially, commercial producers experience a rapid increase in net margin (Figure 4), but this is eroded by increasing costs (associated with larger BS holdings) and eventual decrease in animal prices due to increased meat inventories. Net margins for commercial producers are increased overall, but not by as much as the amount of the subsidy. *Tras patio* producers, in contrast, benefit from the policy in the short-term when sheep prices are above the dynamic equilibrium baseline level, but ultimately see net margins eroded by increased supplies resulting primarily from commercial producers (Figure 5).

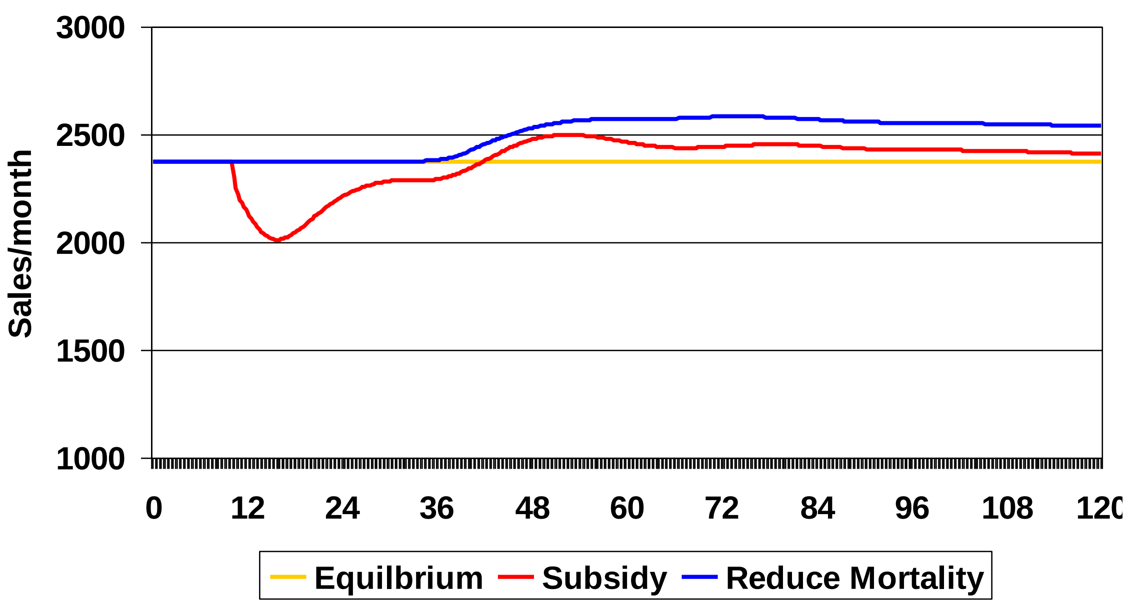

Figure 2. Young Stock Sales, Yucatán Region, for Initial Equilibrium and Two Intervention Alternatives

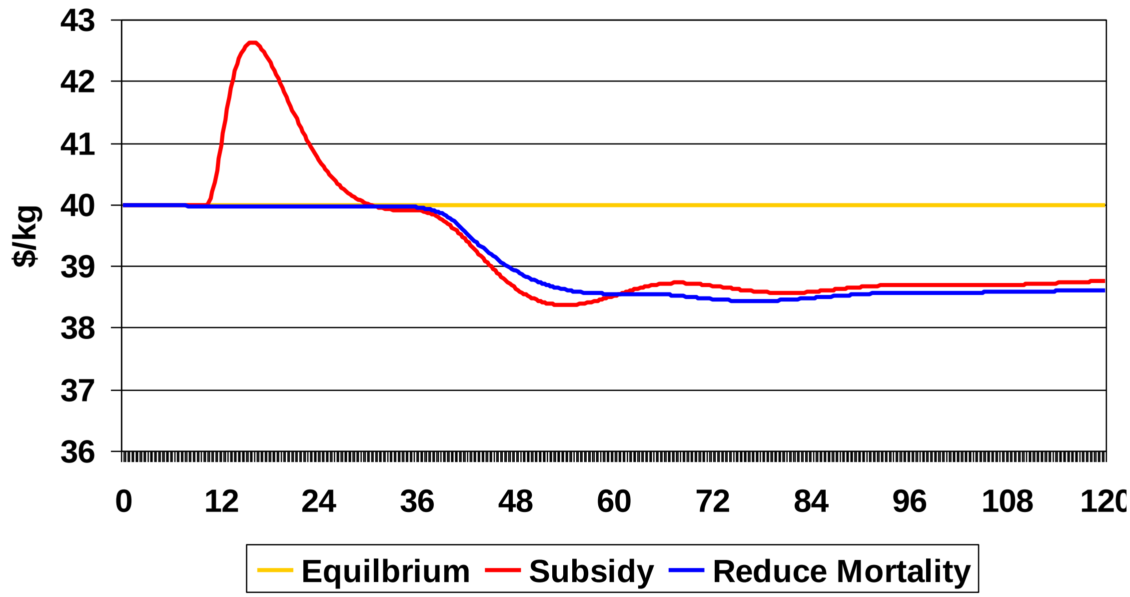

Figure 3. Sheep Meat Price (Pesos/kg) for Initial Equilibrium and Two Intervention Alternatives

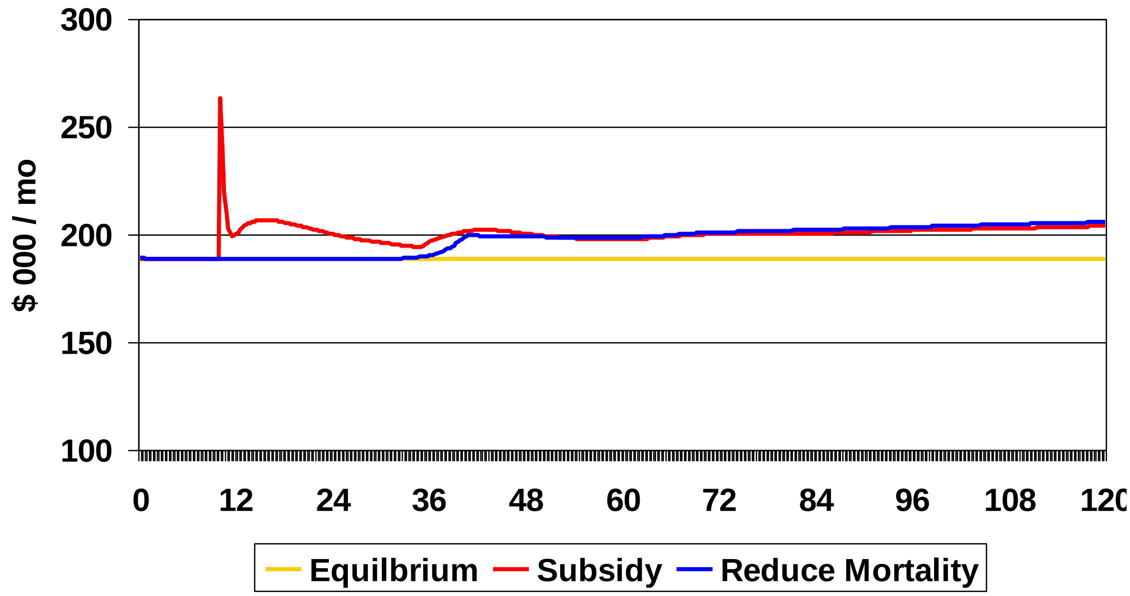

Figure 4. Commercial Producer Net Margin, Yucatán, for Initial Equilibrium and Two Intervention Alternatives

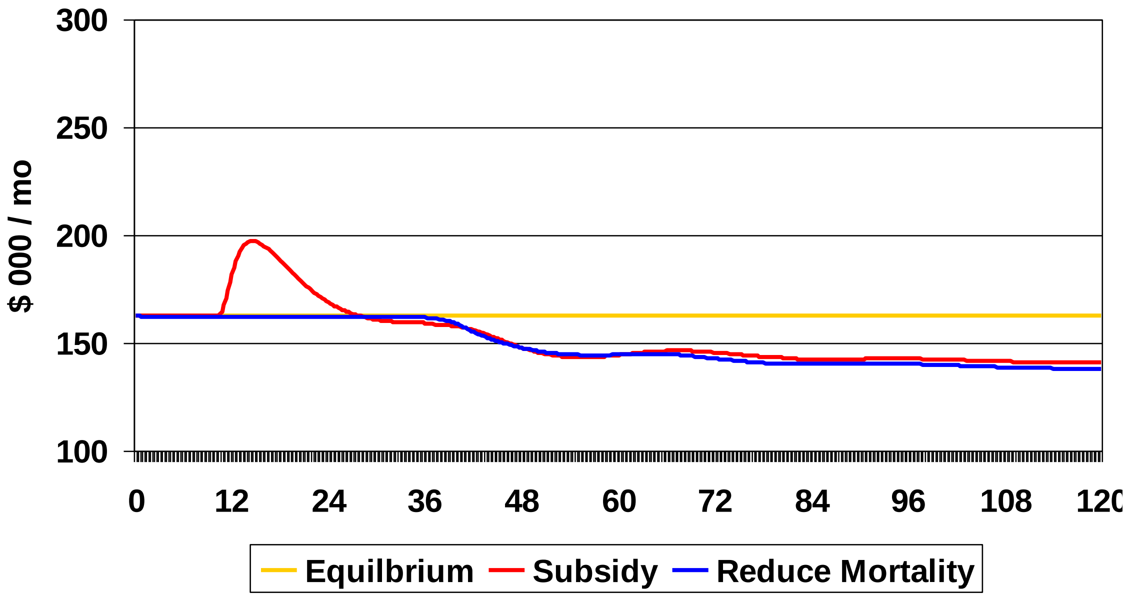

Figure 5. *Tras Patio* Producer Net Margin, Yucatán, for Initial Equilibrium and Two Intervention Alternatives

The impact of the technology to reduce YS mortality, in contrast to the subsidy, produces a gradual increase in YS supplied to the market (Figure 3) and a gradual reduction in sheep meat prices (Figure 2), albeit with low-amplitude oscillations. These patterns of behavior are driven in part by the gradual process of adoption assumed for use of the technology by commercial producers, and by the less direct effect of the intervention on net margin and desired BS. Adoption of the technology increases net margin for commercial producers over time (Figure 4), but also demonstrates oscillatory behavior.[9] Ultimately, the net margins become similar to those under a subsidy: commercial producers see increases in net margin and *tras patio* producers, a reduction. The ultimate outcomes with regard to sheep meat prices derive in part from the assumption of inelastic demand. The subsidy and mortality reductions both increase the supply of animals, and markets respond by reducing prices (which must fall to a larger degree due to inelastic demand). However, it is worth noting that the initial and subsequent outcomes often differ, the ultimate outcomes differ by type of producer (and presumably the impact on *tras patio* producers would be considered undesirable) and that this system demonstrates considerable

[9] Oscillations arise from a system structure that includes at least one negative feedback loop with a significant delay process. In this case, the negative feedback loop involves the response of sheep numbers to higher margins, and the delays are those associated with acquisition of additional BS (i.e., the maturation delay).

policy resistance: the integrated market system responds in a way that offsets the magnitude and sometimes the intended direction of the interventions.

The cumulative outcomes for the health intervention and the subsidy policy under no demand growth are lower mean sheep meat prices, reductions in consumer expenditures (but increased sheep meat consumption), increased cumulative net margin for commercial producers and reduced cumulative net margin for *tras patio* producers (Table 2; first three data columns). Changes in the overall cumulative net margin in the Yucatán are small (less than 0.5% for the subsidy policy and 1.1% for the health intervention), but the direction of change differs for these two interventions. The increase in cumulative net margin for both types of producers in Yucatán due to the cost subsidy constitutes only about 2% of the government expenditures (the increase in cumulative net margin for commercial producers is only 13% of subsidy expenditures), indicating the extent to which policy resistance processes undermine intended outcomes. The principal beneficiaries of both of the interventions are Mexican sheep meat consumers, for whom the change in cumulative expenditures amounts to about $35 to $50 million US dollars over ten years. Thus, the interventions have the (perhaps unintended) consequence of benefiting higher-income sheep meat consumers and larger (and wealthier) commercial sheep producers at the expense of *tras patio* producers (and the government in the case of the subsidies).

Constant Growth Scenarios

In the context of constant growth in sheep meat demand, prices for sheep meat increase continuously over model simulation time regardless of the type of intervention assumed (Figure 6). This rate of increase is not constant over time, however, and differs depending on the intervention. Analogous to the behavior observed in the no growth case, price initially increases most rapidly under the subsidy policy, but after two years remains lower than the price for the scenario without any intervention. The increase in prices is the least rapid and of the smallest magnitude for the intervention to reduce YS mortality. The increases in prices may be misinterpreted (or misrepresented) by policy makers as resulting from their policy actions rather than from the underlying dynamics of demand growth and lags in production response.

Table 2 Simulated Outcomes of Alternative Policy Options Under Three Demand Growth Scenarios

Outcome	No Growth			Constant Growth			Slowing Growth		
	Base	Subsidy	Reduced Mortality	Base	Subsidy	Reduced Mortality	Base	Subsidy	Reduced Mortality
Sheep Meat Price[1] ($/kg)	40.00	39.32	39.09	54.82	53.97	52.79	51.74	51.19	49.95
Diff from DE		-0.68	-0.91	14.82	13.97	12.79	11.74	11.19	9.95
Diff from No Policy		-0.68	-0.91		-0.85	-2.03		-0.56	-1.79
Value of Sales ($ mil)[2]	43,969	43,585	43,454	64,437	63,884	63,160	60,507	60,144	59,388
Diff from DE		-384	-514	20,469	19,915	19,191	16,538	16,175	15,419
Diff from No Policy		-384	-514		-554	-1,277		-362	-1,119
Producer Net Margin[2] ($ mil)									
Yucatán, Commerical	22.7	24.0	23.7	46.2	52.9	49.5	40.1	43.9	43.5
Diff from DE		1.4	1.1	23.5	30.3	26.8	17.4	21.3	20.8
Diff from No Policy		1.4	1.1		6.8	3.3		3.9	3.5
Yucatán, Tras Patio	19.5	18.3	17.9	45.0	42.8	40.5	38.6	37.9	35.9
Diff from DE		-1.2	-1.6	25.4	23.3	21.0	19.1	18.3	16.4
Diff from No Policy		-1.2	-1.6		-2.2	-4.5		-0.8	-2.7
Other, Commercial	2,851.3	2,996.0	3,003.5	4,825.9	5,166.9	5,212.9	4,484.4	4,619.8	4,803.1
Diff from DE		144.7	152.2	1,974.6	2,315.6	2,361.6	1,633.1	1,768.5	1,951.8
Diff from No Policy		144.7	152.2		341.0	387.0		135.4	318.7
Other, Tras Patio	2,309.6	2,214.5	2,177.0	4,328.6	4,228.6	4,068.6	3,944.3	3,881.9	3,706.6
Diff from DE		-95.1	-132.6	2,019.0	1,919.0	1,759.0	1,634.7	1,572.3	1,397.1
Diff from No Policy		-95.1	-132.6		-100.0	-260.0		-62.5	-237.7

Outcome	No Growth			Constant Growth			Slowing Growth		
	Base	Subsidy	Reduced Mortality	Base	Subsidy	Reduced Mortality	Base	Subsidy	Reduced Mortality
Regional Net Margin[2] ($ mil)									
Yucatán	42.2	42.4	41.7	91.1	95.8	90.0	78.7	81.8	79.4
Diff from DE		0.2	-0.5	49.0	53.6	47.8	36.5	39.6	37.2
Diff from No Policy		0.2	-0.5		4.6	-1.2		3.1	0.7
Other	5,160.9	5,210.5	5,180.5	9,154.5	9,395.5	9,281.5	8,428.7	8,501.7	8,509.8
Diff from DE		49.6	19.6	3,993.6	4,234.5	4,120.6	3,267.8	3,340.7	3,348.9
Diff from No Policy		49.6	19.6		241.0	127.0		72.9	81.0
Government Subsidy[2] ($ mil)									
Yucatán	0.0	10.4	0.0	0.0	16.6	0.0	0.0	16.5	0.0
Diff from DE		10.4	0.0	0.0	16.6	0.0	0.0	16.5	0.0
Diff from No Policy		10.4	0.0		16.6	0.0		16.5	0.0
Other	0.0	723.3	0.0	0.0	1,100.4	0.0	0.0	1,066.6	0.0
Diff from DE		723.3	0.0	0.0	1,100.4	0.0	0.0	1,066.6	0.0
Diff from No Policy		723.3	0.0		1,100.4	0.0		1,066.6	0.0

[1] Mean value over 120-month simulation.

[2] Cumulative value over 120-month simulation.

Note: All monetary values are in pesos. The symbol '$" is used to denote this in Mexico. DE indicates dynamic equilibrium.

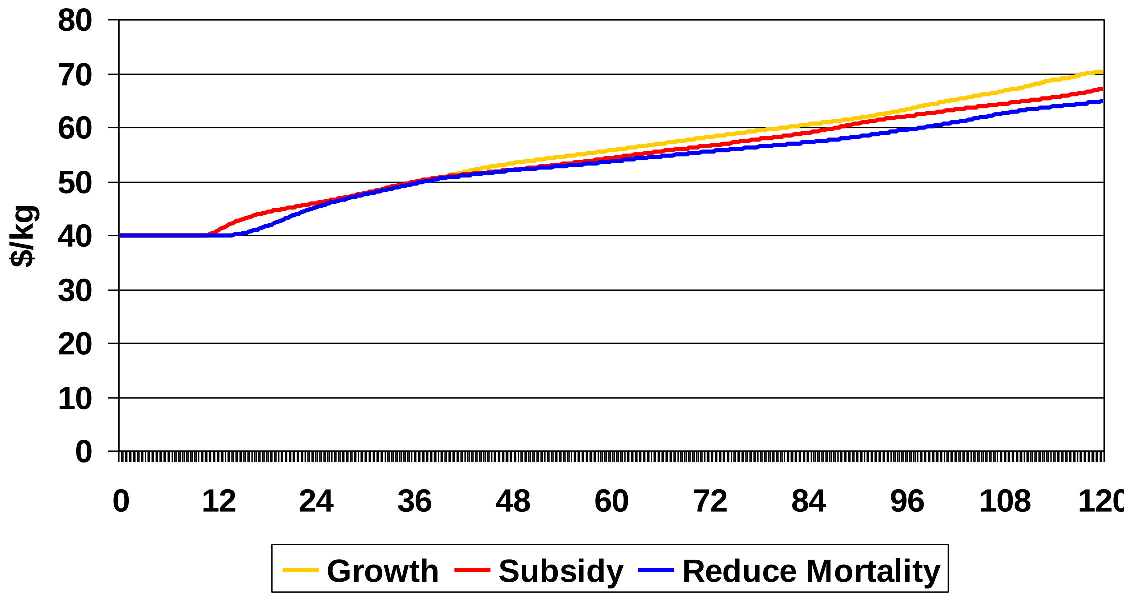

Figure 6. Sheep Meat Price (Pesos/kg) for Initial Equilibrium and Two Intervention Alternatives, with Constant Demand Growth

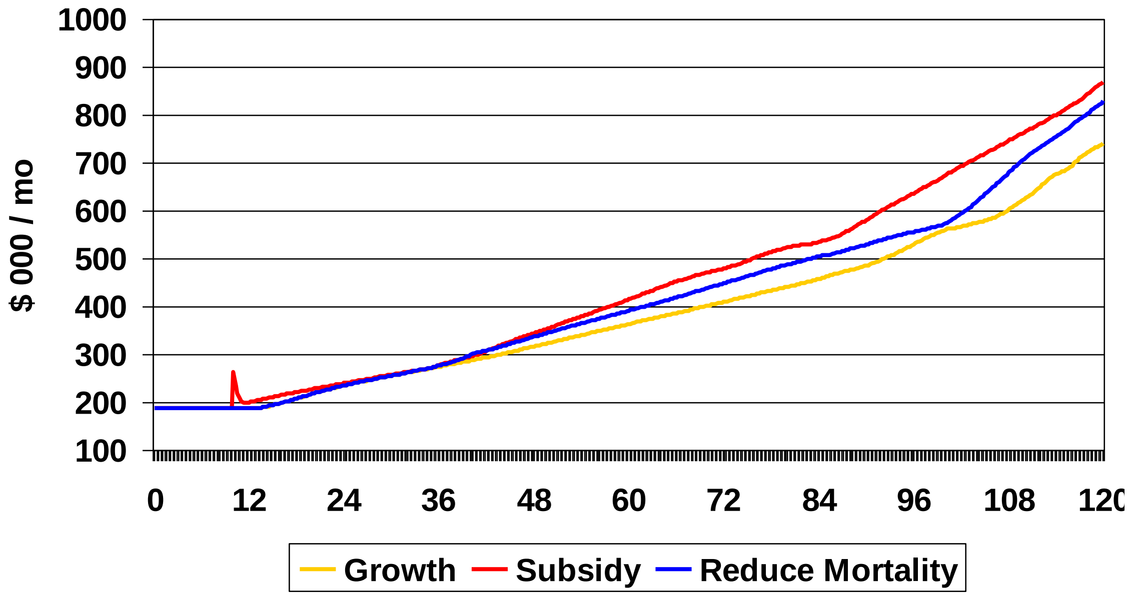

Figure 7. Commercial Producer Net Margin, Yucatán, for Initial Equilibrium and Two Policy Alternatives, with Constant Demand Growth

Despite the appearance of robust growth in sheep production and prices, sheep meat and animal prices are in fact lower than they would have been in the absence of the interventions, again consistent with outcomes observed for no growth case.

The impacts of the interventions on sheep producer net margin mirror those of the no growth case. Commercial sheep producers see an initial dramatic increase in net margin upon introduction of the subsidies (Figure 7, previous page), a period when net margin with the subsidy is roughly equal to that without subsidies, then a period of increasing difference due to the subsidy. In this case, the effects of growth over the long term dominate the initial response of commercial producers to the subsidy, and net margins continue to rise over the 10-year period. Net margins are initially larger than they would have been without interventions for *tras patio* producers due to relative reduction in YS sales by commercial producers and the associated more rapid price increase (Figure 8). By two years after the introduction of the interventions, however, net margins are smaller for *tras patio* producers because the decrease in prices is not compensated by either a corresponding reduction in variable costs or increased sales.

In cumulative terms, constant demand growth without other interventions results in a 37% increase in the mean sheep meat price over the model simulation time, a 46% increase in the cumulative value of sheep meat sales (due to both price and quantity increases) and a 116% increase in regional net margin for Yucatán sheep producers (Table 2). The impacts of the interventions generally are to decrease each of these values by a small amount. Commercial sheep producers in Yucatán benefit from interventions in the context of demand growth and *tras patio* producers are made worse off. As for the case of no demand growth, increases in cumulative net margin realized by both types of sheep producers are small compared to government expenditures on subsidies, but the proportion of subsidy expenditures realized as net margin gains by producers in Yucatán increases from 0.5% to 27.8%. The effects of growth dominate the effects of the interventions and the likely interpretation by policy makers is that their interventions deserve much of the credit for sustained growth of the sheep sector.

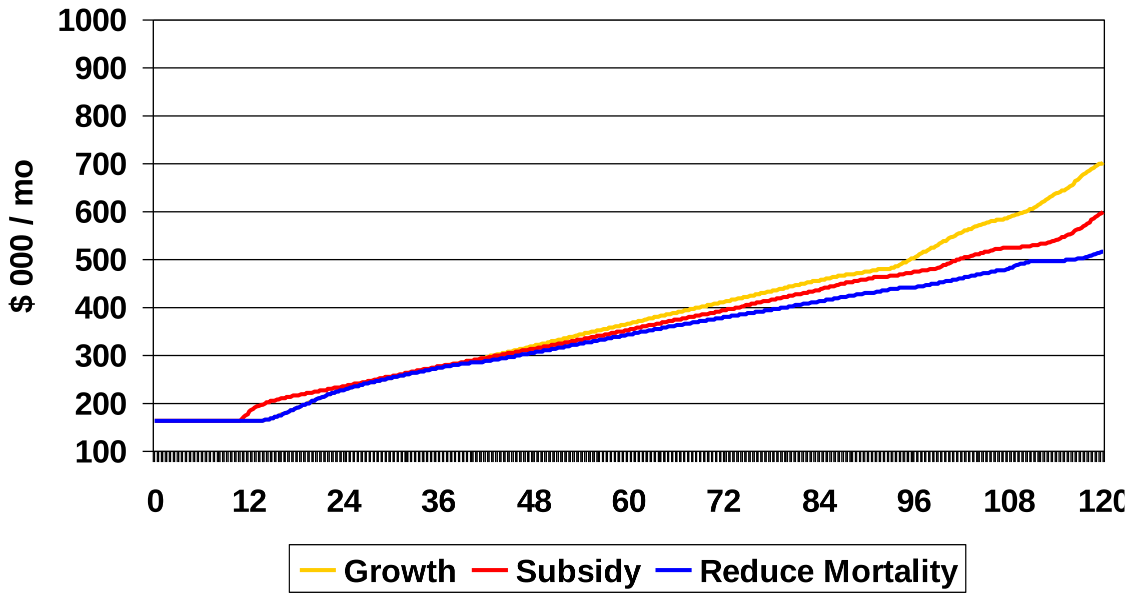

Figure 8. *Tras Patio* Producer Net Margin, Yucatán, for Initial Equilibrium and Two Policy Alternatives, with Constant Demand Growth

Slowing Growth Scenarios

If demand growth were to slow to less than half its current annual rate after four years of model simulation time, the results are qualitatively similar to those with constant growth, but somewhat attenuated.[10] Demand growth that slows over time still results in markedly increased sheep meat prices, consumer expenditures on meat sales, and sheep producer net margins (Table 2). The impacts of the interventions on prices and the value of sheep meat sales in the context of slowing growth are qualitatively similar to the constant growth case, but the magnitude of the impacts is somewhat reduced. This suggests that the magnitude of the policy impacts depends to a certain extent on the rate of demand growth relative to the ability of the sheep production sector to respond given the inherent biological delays and the assumed producer decision making structure. Slowing growth does not alter the outcome that the principal beneficiaries of interventions in the sheep production sector are higher-income consumers, that commercial sheep producers benefit from the policy and that *tras patio* producers experience reductions in

[10] Because the graphical results in particular are qualitatively similar to those for constant growth, only tabular results are presented for these scenarios.

net margin. Nor does the growth rate change modify the limited effectiveness of the subsidy expenditures for increasing producer net margin. In fact, slowing growth reduces the proportion of subsidy expenditures realized by commercial producers as net margin.

Conclusions and Implications

The foregoing analyses suggest that rapid growth in the demand for sheep meat in Mexico will generate increased earnings for both commercial and *tras patio* sheep producers over the next decade. The growth in demand dominates the effects of policies designed to assist the sheep sector, whether through direct production subsidies or research to support technological interventions that reduce animal mortality. The policies, in fact, have the impact of primarily benefiting Mexican sheep meat consumers, many of whom tend to be higher-income urban residents, and inevitably reduce net margins (relative to no interventions) for smaller, resource-poor *tras patio* producers. Thus, as a strategy for rural development, the policies have decidedly mixed results and the effectiveness of government expenditures—in terms of benefits for producers—is quite limited. The Mexican sheep system thus exhibits two characteristics of dynamically complex systems: unintended consequences (e.g., reduced cumulative net margins for all sheep producers in some cases as a result of policy) and policy resistance—the ability of the endogenous response of the system to various incentives to limit the ability of policy to achieve specified objectives[11].

Although the principal results of the modeling effort discussed above are specific to the case of sheep production in Mexico and the specific interventions analyzed, there are also a number of broader implications. The first concerns the usefulness of an approach to modeling systems evolution that addresses both policy and technology options as a part of the process. In this case, the system evolution is driven externally by exogenous demand growth (i.e., the drivers of that demand growth change are not modeled), but also internally by the stock-flow-feedback structure and behavioral responses assumed to characterize the system. Although it is easy to imagine extensions of this model to better represent the drivers of change and the evolution of

[11] It is also worth noting that in conversations with numerous state government and research officials in Mexico that they have not always clearly defined a set of consistent objectives for the livestock sector or agriculture and rural development more generally.

production technologies, the above analyses illustrate in a relatively simple and stylized case the practicability of system evolution analyses that include policy and technology factors.

Second, this application of a dynamic model highlights the usefulness of what has sometimes been termed the "complex systems" approach to analysis of agricultural systems. As mentioned in the introduction, some authors believe that most social, economic, biological and other natural systems can be usefully conceived of as dynamically complex (Rosser, 1999; Sterman, 2000; Allen and Strathern, 2005). Thus, these systems can generate a variety of behavioral modes and outcomes that differ in the short and long term. The concepts and conclusions underlying this general school of thought are not frequently applied in models of agricultural systems, but they may prove useful for predicting future systems evolution with policy and technological interventions. According to this school of thought, unexpected future developments may arise due to the nonlinear characteristics of the system, past behaviors (and therefore statistical relationships or correlations) may not be a good guide to the future, and simplification through aggregation may ignore essential elements of system structure and undesirable elimination of potential behavioral modes. This perspective on modeling extends also to model evaluation, suggesting that neither parsimony nor independent verification are always possible when the production system of interest may display dynamically complex behavior. The use of a systems approach that emphasizes the development of both conceptual and empirical causal models often will be most appropriate for these systems.

Finally, this process of undertaking this research has underscored the benefits of interdisciplinary collaboration to assess technology and policy options. A simplified version of this model has been used as a pedagogical tool for high-level agricultural researchers in INIFAP. Because they had not previously been exposed in any detail to economic concepts, they did not realize the importance that a parameter such as the demand elasticity could play in the determination of outcomes related to their principal mission of developing technologies to benefit agricultural producers in Mexico. Conversely, however, there is often a benefit to economic analyses of more detailed representation of the stock-flow-feedback dynamics found in all agricultural production and market systems. Applied biological scientists working collaboratively with economists to develop more appropriate systems-oriented models often can provide both better policy answers and more robust learning processes.

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APPENDIX: Model Equation Specification

BS and YS Dynamics

$$BS_{rpt} = \int\left(Replacements_{rpt} + Adjustments_{rpt} - Culls_{rpt}\right) + BS_{rp0} \quad \textbf{(1)}$$

This equation indicates that the number of breeding stock is the integral of replacements for culled animals, adjustments based on desired increases in the number of BS held less the number of animals culled. In this and subsequent expressions, *r* indicates region (Yucatán or Other), *p* indicates producer type, and *t* is the time subscript.

$$\frac{d\left(BS_{rpt}\right)}{dt} = Replacements_{rpt} + Adjustments_{rpt} - Culls_{rpt} \quad \textbf{(2)}$$

This is the equivalent differential equation for the integral equation shown in (1).

$$YS_{rpt} = \int\left(Births_{rpt} + Mortality_{rpt} + Maturation_{rpt}\right) + YS_{rp0} \quad \textbf{(3)}$$

This is the integral equation for YS, which indicates that births increase YS numbers whereas mortality and maturation (to the age for sale or use as a BS replacement animal) reduce YS numbers.

$$\frac{d\left(YS_{rpt}\right)}{dt} = Births_{rpt} - Mortality_{rpt} - Maturation_{rpt} \quad \textbf{(4)}$$

This is the equivalent differential equation expression for (3).

$$Births_{rpt} = DELAY[Breeding_{rpt}, Gestation\,Time_{rpt}] \quad \textbf{(5)}$$

This indicates that the birth rate is a fixed delay of the rate at which animals are bred, where the delay duration is the gestation time.

$$Breeding_{rpt} = BS_{rpt} \cdot \left(\frac{LPL_{rp}}{LI_{rp}}\right) \quad \textbf{(6)}$$

The breeding rate is equal to the number of BS times the Lambs per Lambing (LPL) divided by the Lambing Interval (LI).

$$Mortality_{\mathrm{rpt}} = DELAY[Births_{rpt} \times q_{rpt}^{Mortality}, MatTime_{rpt}] \quad \textbf{(7)}$$

Mortality is a fixed delay of births times a proportional mortality rate, with the delay equal to a time required for maturation. Note that this is one of two commonly used formulations for mortality in aging-chain and population models (Sterman, 2000). The other formulation assumes a first order delay process rather than removing all mortality (and maturing animals; see below) when cohort members exit.

$$Maturation_{\mathrm{rpt}} = DELAY[Births_{rpt} \times \left(1 - q_{rpt}^{Mortality}\right), MatTime_{rpt}] \quad \textbf{(8)}$$

Maturation is a fixed delay of births times one minus a proportional mortality rate, with the delay equal to a time required for maturation.

$$\theta_{rpt}^{Mortality}, MatTime_{rpt}, LI_{rpt} = f(FeedBiomass_{rpt}, BS_{rpt} + YS_{rpt}) \quad (9)$$

The mortality rate, the maturation time and the lambing interval are nonlinear functions decreasing in the relative availability of feed.

$$Maturation_{rpt} = Sales_{rpt}^{YS} + Replacements_{rpt} \quad (10)$$

This condition implies that all maturing (female) animals at time *t* are either sold or retained as BS replacements.

$$Replacements_{rpt} \leq Maturation_{rpt} \cdot \theta^{Female} \quad (11)$$

The number of replacements available must be less than or equal to the number of YS reaching maturation age time the proportion of the YS that is female.

$$Slaughter_{t} = \sum_{rp} Culls_{rpt} \cdot Yield^{BS} + \sum_{rp} Sales_{rpt}^{YS} \cdot Yield^{YS} \quad (12)$$

The slaughter rate (in terms of kg of sheep meat per month) is the number of BS animals culled times the carcass yield for BS plus sales of YS times the carcass yield for YS.

Feed Resource Dynamics

$$Feed_{rpt} = \int \left(Production_{rpt} + Losses_{rpt} + Consumption_{rpt} \right) + Feed_{rp0} \quad (13)$$

Feed resources available are the integral of feed production, losses (feed not consumed that becomes senescent and decays) and feed consumed by animals.

$$\frac{d\left(Feed_{rpt}\right)}{dt} = Production_{rpt} - Losses_{rpt} - Consumption_{rpt} \quad (14)$$

This is the differential equation representation of (16).

$$FeedPerLand_{rpt} = f\left(FeedBiomass_{rpt}, MaxBiomass_{rpt}, Rain_{rt}\right) \quad (15)$$

Feed produced per unit land is a decreasing nonlinear function of current forage or browse biomass relative to the maximum possible biomass and current month rainfall.

$$Losses_{rpt} = Biomass_{rpt} \cdot \theta_{rp}^{Loss} \quad (16)$$

Losses of feed are a constant proportion of current forage or browse biomass.

$$Consumption_{rpt} = BS_{rpt} \cdot FeedPerBS_{rpt} + YS_{rpt} \cdot FeedPerYS_{rpt} \quad (17)$$

Feed consumption equals feed consumed by BS and by YS, where consumption by each of those animal types is equal to the number of current animals times the amount of feed consumed per animal per month.

$$FeedPerBS_{rpt}, FeedPerYS_{rpt} = f(Biomass_{rpt}, BS_{rpt} + YS_{rpt}) \quad (18)$$

Feed consumed per animal per month is a function of the relative availability of feed, which is in turn a function of the current forage or browse biomass and the numbers of BS and YS.

Inventory and Price Dynamics

$$\frac{d(Inventory_t)}{dt} = Slaughter_t - Sales_t + Imports_t \quad (19)$$

Sheep meat inventories are increased by the slaughter rate and imports and decreased by sales.

$$Imports_t = Imports^{REF} \cdot \left(\frac{P_t^{Meat}}{P^{REFMeat}} \right)^{\varepsilon} \quad (20)$$

Sheep meat imports are an increasing function of Mexican sheep meat prices, formulated as a reference level of imports times current sheep meat price relative to a reference meat price value with an import demand elasticity $\varepsilon > 0$. Note that there are few trade barriers for sheep meat entering Mexico.

$$Sales_t = Sales_t^{REF} \cdot \left(\frac{P_t^{Meat}}{P^{REFMeat}} \right)^{\eta} \quad (21)$$

Sheep meat sales are a decreasing function of Mexican sheep meat prices, formulated as a time-dependent reference level of sales times current sheep meat price relative to a reference meat price value with own-price demand elasticity $\eta < 0$. Growth in demand for policy scenarios is effected through increases in the value of “reference” sales over time.

$$P_t^{Meat} = P^{REFMeat} \cdot f\left(Inventories_t, Sales_t\right) \quad (22)$$

Sheep meat prices are determined in response to a smoothed value of inventory coverage (inventories at time t divided by sales at time t, which has units of the number of months for which inventories are sufficient to cover the current rate of sales). Prices are a nonlinear decreasing function of inventory coverage.

$$P_{rpt}^{BS} = \left(P_t^{Meat} - Costs_{rp}^{BSMarketing}\right) \cdot Yield^{BS} \quad (23)$$

Prices per BS animal received by sheep producers are equal to the sheep meat price less meat marketing costs (which differ by producer type and region) adjusted by the yield in kg per animal.

$$P_{rpt}^{YS} = \left(P_t^{Meat} - Costs_{rp}^{YSMarketing}\right) \cdot Yield^{YS} \quad (24)$$

Prices per YS animal received by sheep producers are equal to the sheep meat price less meat marketing costs (which differ by producer type and region) adjusted by the yield in kg per animal.

Producer Decision Dynamics

$$BS_{rpt}^{*} = BS_{rpt} \cdot f\left(Net\ Margin_{rpt}\right) \quad (25)$$

The desired (aggregated by producer group and region) level of breeding stock is equal to the current number of BS times a nonlinear increasing function of expected long-run net margin (an exponential smooth of past net margin values) relative to a reference net margin value. The functional form is constant elasticity, with an elasticity of BS^* with respect to long-run net margin of $\xi > 0$. Note that this uses an anchoring and adjustment heuristic that Sterman (2000) argues is commonly used in capacity decisions.

$$MTBS_{rpt} = f\left(\frac{BS^*_{rpt}}{BS_{rpt}}\right) \quad (26)$$

The mean time an animal is retained in the BS stock is a nonlinear increasing function of the ratio of desired to current breeding stock.

$$Replacements_{rpt} = \frac{BS^*_{rpt}}{MTBS_{rpt}} \quad (27)$$

The number of animals to be replaced is a first-order expression involving the number of desired BS animals and the mean time animals are retained as BS (MTBS).

$$Adjustments_{rpt} = \frac{BS^*_{rpt} - BS_{rpt}}{BSAT_{rpt}} \quad (28)$$

Adjustments are animals added to the BS in response to changes in the desired level of BS holdings. They are expressed as a first-order expression of the difference between current and desired levels of BS holdings, modified by a parameter representing the time required to adjust BS holdings (BSAT).

$$Culls_{rpt} = \frac{BS_{rpt}}{MTBS_{rpt}} \quad (29)$$

Animals are culled at a fractional rate of animals currently held as BS. This fractional rate equals (1/MTBS).

$$YSSales_{rpt} = Maturation_{rpt} - \left(Replacements_{rpt} + Adjustments_{rpt}\right) \quad (30)$$

Sales of YS by the sheep producer are limited by the maturation rate. Animals not needed for replacements or adjustments due to changes in the desired breeding stock are assumed to be sold.