AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Modeling the Impacts of Alternative Invasive Species Management Policies on Livestock Production*

ZISHUN ZHAO

THOMAS WAHL

RICARDO DIAZ

IMPACT Center, Washington State University
IMPACT Center
123 Hulbert Hall
PO Box 646214
Washington State University
Pullman, WA 99164-6214
email: zishun@wsu.edu

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado, July 1-4, 2004

Copyright 2004 by Zishun Zhao, Thomas I. Wahl, Ricardo Diaz. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.
**The research presented in this paper is fully funded by the Program of Research on the Economics of Invasive Species Management (PREISM) at USDA's Economic Research Service.*

Modeling the Impacts of Alternative Invasive Species Management Policies on Livestock Production

Introduction

Invasive species (IS) pose a serious threat to not only to the natural environment, but also to agriculture and human health. The introduction of an invasive species could devastate a country's agricultural production. Especially in the livestock sector, an introduced animal epidemic could spread very fast and cause severe symptoms because the native animals have no natural immunity. It could also drastically damage our food security. Both as mammals, human and livestock share a fare amount of common diseases, which could be passed to human easily through the consumption of meats where pathological agents are abundant if the animal was sick.

Due to these reasons, an IS outbreak could cause great economical and social consequences. The 1997 outbreak of foot and mouth disease in Taiwan resulted in the loss of 38% of their pig inventory. A single mad cow found in Alberta, Canada, at its peak was costing Canada $25 million per day (Dennis Laycraft, Canadian Cattlemen's Association executive vice president). The recent outbreak of mad cow (BSE) in Washington State has stopped virtually all exports of US beef and according to Gregg Doud, an economist for the National Cattlemen's Beef Association, the US stood to lose at least 6 billion dollars a year in exports and falling domestic prices because of the sick cow. The US beef industry is facing perhaps its most severe challenge to date.

The great economic potential consequences of the IS have drawn a lot of economists' attention and literature on this subject is abundant. However, Much of the existing literature on IS focuses on evaluating the (potential) economic effect of an invasive species (e.g. Ekboir et al. 2003). As discussed by Maguire (2001), many of these studies suffer from "separating risk assessment from risk management, thus disrupting essential connections between the social values at stake in invasive species decisions and the scientific knowledge necessary to predict the likely impacts of management actions."

We develop a conceptual framework for modeling meat production and consumption that not only fully captures the effects of the introduction of an IS, but also evaluates the benefit of alternative IS management policies. The main objective of the modeling framework is to make it general enough to accommodate all different livestock animals, and yet easily implementable for each. The model is built with in mind the need of government agencies to assess the cost and benefits alternative IS management policies and to allocate scarce resources to achieve maximum social welfare.

In this paper, the general modeling framework is first laid out and then an implemented beef production and consumption simulation model is presented as an example. Preliminary simulation results are provided to demonstrate the validity and stability of the model.

The Conceptual Framework

Livestock production is using living animals as growing machines to produce meat. The production process is constrained by the biological life cycle of the animals. Naturally, the whole process can be broke down into two pieces, breeding and feeding. The total supply of meat is very much determined by the decision to save and bred the female animals. The fact that the female animal can serve both as a breeding animal and as a feeder makes the decision problem a capital-pricing model. As soon as the breeding decision is made, the ones that are not retained for breeding will be fed for meat (assuming there is no slaughtering of baby animals). The feedlot then chooses an optimal slaughter point to maximize unit profit.

Population Dynamics (Live Animal production)

We start the model specification with the evolution of the breeding stock population. Follow Aadland (2002), the breeding stock is differentiated by ages (to be general, age could be in months, quarters, and/or years). Each age group evolves according to the following equations:

$$(1) \qquad K_{t+1}^{j+1} = (1-a_t^{\,j})(1-d^{\,j})K_t^j + M_t^j - E_t^j$$

where K_t^j, M_t^j and E_t^j are the number of domestic, imported, and exported breeding females of age *j* respectively, $a_t^{\,j}$ is the percentage to be culled (choice variable) for that group, q is birth rate, and B_t is the number of productive females. The equation says that the female animals of age *j* that live through the period together with the imported age *j* animals minus the exported during the period would progress into age *j*+1 in next period. The total number of female animals B_t that can be bred is given by

$$(2) \quad B_t = \sum_{j=m}^{s} K_t^j$$

where m is the age at which a female is ready to be bred, s is the age the productive life ends. These females could be bred and give birth in next period. Instead of birth rate, “weaning rate”, the probability of weaning a healthy offspring, q serves better to describe the productivity of a breeding animal. The newborns are given by

$$(3) \quad K_{t+1}^0 = 0.5q\,B_t \qquad M_{t+1}^0 = 0.5q\,B_t$$

with K_{t+1}^0 and M_{t+1}^0 being the female and male newborns respectively. With these equations, population of each category for every period is attainable once the initial stocks and the time path of the culling rates are given.

Meat Production

All of the male newborns and the female that are not retained for breeding purpose and not exported will go through a feeding program to produce meat. Theoretically, the producer could choose different feeding methods, such as limiting intake and/or changing ration composition according to the life stage and body condition of the feeders, to maximize their profit. Some of the big feedlots are actually doing so. However, most of the producers don’t have the knowledge and resources. More often, the feeders will go through a fixed “optimal” feeding program suggested by animal scientists. Thus, to simplify matters, we assume all the feeders go through a typical feeding program and only allow the producers to choose when to slaughter them. Under the feeding program, let the growth function and cost function be

(4) $G_t = f(t)$ $\qquad C_t = c(t)$

we use the Greek letter t to allow a different length of time interval (usually on daily base in feedlots) from that of the breeding decision. Let p_t be the market price of the meat (on live weight base), the profit as a function of t is

(5) $PF_t = p_t G_t - C_t$.

Thus, the feedlot optimization problem is a linear search for the t^* that gives the maximum unit profit PF_t^* (assuming constant return to scale). The decision to import and export feeders could also be handled by the feedlot optimization. The feedlot will import feeders as long as the optimal unit profit (with importing cost being part of the cost) is higher than zero. The feedlot will export feeders so long as the revenue from exporting one is higher than the optimal unit profit. The slaughter weight of the finished animals is predicted as $G_t^* = f(t^*)$. Total meat supply from domestic raised animals (excluding meat from animals imported for slaughtering) is then $S_t = G_t^*(a_{t-t}^0 K_{t-t}^0 + M_{t-t} + NMF_{t-t})$ with t converted to the same scale as t and NMF_t being the net imports of feeders.

Inventory Update Policy

The breeding decision is to choose a series of culling rates, imports, and exports to maximize the total profit subject to the above biological constraints. Total revenue consists of meat sales, live animal exports, and salvage value of culled breeding animals. With pw_t^j as the world price for breeding animal of age *j* (per animal), the total revenue is given by

(6) $R_t = PF_t^*(a_{t-t}^0 K_{t-t}^0 + M_{t-t}^0) + \sum_{j=0}^{s} pw_t^j E_t^j + \sum_{j=1}^{s} SV_t^j a_t^j K_t^j$

with t converted to the same scale as t. Let MC_t^j be the unit maintenance cost breeding animal of age *j*, the total cost of the breeding herd is the total maintenance cost plus the cost of imports

$$(7)\quad TC_t = \sum_{j=0}^{s} (MC_t^j K_t^j + pw_t^j M_t^j)\,.$$

The total profit for period *t* is

$$(8)\quad p_t = R_t - TC_t\,.$$

And the producer's objective is to maximized the sum of the present values of all future profit by choosing the culling rates, imports and exports

$$(9)\quad obj = \underset{\{E_t^j\},\{M_t^j\},\{a_t^j\}}{MAX} \{\sum_{t=0}^{\infty} b^t E_0(p_t)\}$$

subject to the constraints of (1),(2),and(3).

Equations (1)-(9) complete the specification of the meat production process. Due to the complexity of the biological process, a close form solution for the maximization problem is not practical.

Markets and Equilibrium Conditions

The Almost Ideal Demand System (AIDS) is employed to define the domestic demand because it take into account the substitution effect as price changes and has the capability to generate exact welfare measures (Compensated Variation *CV* and Equivalent Variation *EV*) (Deaton and Muellbauer 1980). If we let D_t be the demand vector, P_t be the price vector, and IN_t be the income, the demand system in price dependent form can be expressed as

$$(10)\quad P_t = F(D_t, IN_t)\,.$$

Since we do not explicitly model the meat packing industry, the demands discussed here are the demands net out the meat from animals imported solely for the purpose of slaughtering. In the case of free trade, the export demand for meat would depend on the domestic price

(11) $ME_t = EDf(P_t)$.

Given that in most countries the volume of live animal trade for breeding is very small and most of the import and export are for the purpose genetic improvement, it doesn't severely impair the model by setting the import and export terms in equation (1) as exogenous variables. However, as important pathways for invasive diseases, they cannot be totally ignored.

The market-clearing price for import of feeders Pfm_t^* is the one that makes the profit of feeding them zero. The number of imported feeders is given by the foreign supply at this price $MF_t = FFS(Pfm_t^*)$. The market-clearing price for export of feeders Pfe_t^* is the one that equate the revenue from exporting to the marginal unit profit from feeding. And the number of exported feeders is given by $EF_t = FFD(Pfe_t^*)$ with $FFD(\bullet)$ being the foreign feeder demand function. When a country engages in both importing and exporting feeders, the equality $Pfm_t^* = Pfe_t^*$ is dictated by the trade arbitrage.

For the market-clearing condition of meat, let $MM_t = FMS(P_t)$ be the foreign meat supply function and $EM_t = FMD(P_t)$ be the foreign meat demand function. Then the market-clearing price is the solution of

(12) $S_t + MM_t = D_t + EM_t$.

Both the imports and exports can be segmented into different countries or trade regions to better accommodate different trade policies and bilateral agreements between the home country and the others. The meat import can also include live imports for direct slaughtering with a fixed price markup to avoid explicit modeling of packing industry. Although in short run the fixed price markup might not be describing the actual price difference, it could very well represent the difference in processing cost in the long run.

By now, the conceptual model of livestock production is completely specified. With a proper choice of time interval, mature age, length of productive life, feeding pattern, growth function, and other biological parameters, a simulation model could be built and used to evaluate the effects of various events and agricultural policies on different aspects of the livestock production.

Modeling the Impacts of IS and IS policies

Any IS or IS management policy would either alter the population dynamics of the breeding stock or change the growth function of the feeders (including changes in the input requirements). Most diseases will change one or more of the parameters including the birth rate, death rate, feed intake, feed efficiency, and etc. Some of them could contaminate the meat and make it unsafe for consumption. Before we could proceed to evaluate the economic consequences of an IS, the scale of spread of the IS need to be specified. Let X_t^j be the population of the breeding stock affected by the IS, $e_t * \sum \mathrm{X}_t^j$ be the population susceptible (in direct or indirect contact with animals that disseminate the pathogens), r be the probability of being affected after contact, and Δ_t^j be the population for which the IS is eliminated (healed, self-healed, killed, dead). Then the dynamics of the affected breeding stock is given by

$$(13)\quad X_{t+1}^{j+1} = r * \min\{(e_t * \sum X_t^j), (K_t^j - X_t^j)\} + X_t^j - \Delta_t^j + m_t .$$

where m_t is a non-negative random variable representing the introduction of an IS. This dynamic process can be supported by the expected outcome of a state-transition model (Ekboir et. al. 2003; Miller 1979). The whole population can be divided into two groups—affected and non-affected. The non-affected (or part of it) can be treated as exposed population with the probability of getting affected, $l_t = \frac{r * \min\{(e_t * \sum X_t^j), (K_t^j - X_t^j)\}}{K_t^j - X_t^j}$. Now the producer's decision problem consists of two parts—one for the affected population with the altered parameters for certain and the other for the non-affected population with a set of parameters binomially distributed (normal parameters with probability $1 - l_t$ and altered parameters with probability l_t), both with the knowledge that r percent of the offspring born by the affected mothers (could be higher if inheritance is possible) would be affected by the IS and have a different growth function from that of the unaffected ones. An equation similar to (12) with a different parameter value for e_t and one more term representing the affected feeders coming from the breeding herd is specified to represent the propagation of the IS among feeders on feedlots.

The introduction and establishment of an IS depends on the inflow of hosts or media as well as the border control and quarantine policy. If the border control would let through a host or media with probability *p*, then m_t in equation (2) follows a geometric distribution with density function $f(m_t) = p^{m_t}(1-p)^{H_t - m_t}$ where H_t is the total number of hosts that's coming through the border. Similarly, we could define Δ_t^j to be a random variable, also geometrically distributed with density function $f(\Delta_t) = y^{\Delta_t}(1-y)^{X_t^j - \Delta_t}$ where y is the probability of an affected animal being detected and eliminated. y can be thought of as a measure of the effectiveness of the domestic control policy. Suppose for any IS management scheme, we know the corresponding p and y, the framework described above could then give us the distribution of the total social welfare—the sum of the producers' surplus and the consumers' *CV* or *EV*.

The model could adequately incorporate the effects of any invasive species management on the introduction and spread of the IS. The effects of prevention measures, including border control, quarantine measures, offshore inspection, controlling the IS in the source country, and etc, can be represented by reduction in the probability of introduction. The effectiveness of domestic control infrastructure and methods can be represented by the probability of detecting and eliminating the IS. Choices of emergency response measures can be represented by their effects on the spread speed parameter r (through inoculation) and the susceptibility parameter e_t (quarantine measures).

The spread model has direct implications as to the resource allocation among prevention and controlling methods. First, since all prevention measures enter the model in the form of reduction in introduction probability, the marginal costs of the reduction should be equal among all prevention measures. Secondly, no matter how small the probability of introduction is, the IS outbreak will happen sooner or later.

The effort of prevention is just to prolong the expected intervals between outbreaks and thus reduce the economic losses. Thus, any invasive species management scheme should include domestic monitoring and emergency response measures. Third, there is a trade off between prevention and controlling. The marginal benefit of prevention must equal the marginal benefit of controlling, which indicates that the resource allocation for preventing and controlling different species could be very different. For species that spread fast and hard to eliminate, relatively more resources should be directed to prevention. On the other hand, for species that's very costly to detect but spread very slowly, relatively more resources should be spent on domestic monitoring and controlling. Lastly, the producer's confidence in government agencies effectiveness in controlling the IS plays important role in reducing the economic loss. The producer's perception of the susceptibility parameter will change the probability he assigns to the healthy population becoming affected. Overestimate and underestimate will result in less than optimal decisions and greater economic loss due to inefficient use of resources.

Beef Production Model: An Implementation and Illustrative Example of the Conceptual Framework

Among all livestock productions in the US, the beef production is the most important one and perhaps the most complicated one to model. We implemented a simulation model of beef production to illustrate the validity and stability of the model when dramatic shocks to the production parameters and inventory occur.

Population Dynamics

An annual model can best describe the beef production due to the annual reproductive cycle of the breeding herd. A heifer becomes productive at age 2 and the average productive life ends at 10 (Aadland 2002). So we set $m = 2$ and $s = 10$ in equation (2). Typically, the weaned calves not retained for breeding purpose will go through a backgrounding phase and enter feedlots when they become yearlings where they are fed a ration with high grain content. Two more inventories are added to keep track of the number of female and male yearlings:

$$\begin{aligned} Fyg_t &= a^0_{t-1}(1-d^0)K^0_{t-1} \\ Myg_t &= (1-d^0)M_{t-1} \end{aligned}.$$

Feedlot Optimization

The equations for predicting the intake and growth of the feeders on feedlots are adopted form the *Nutrient Requirements of Beef Cattle* (National Research Council, 1996) and listed below.

$$DMI_t = DMA * BW_{t\text{-}1}^{\ 0.75}(0.2435NE_{ma} \text{ - } 0.0466NE_{ma}^2 \text{ - } 0.0869) / NE_{ma}$$

$$NE_{rm} = 0.077BW_{t\text{-}1}^{\ 0.75}$$

$$FFM_t = NE_{rm} / NE_{ma}$$

$$NE_g = (DMI_t \text{ - } FFM_t)NE_{ga}$$

$$G_t = 13.91NE_g^{\ 0.9116}WE_{t\text{-}1}^{\ \text{-}0.6837}$$

$$BW_t = BW_{t\text{-}1} + G_t$$

where DMI_t is the predicted dry matter intake, BW_t is the current body weight (shrunk weight), NE_{ma} is the net energy fro maintenance of the feed, NE_{rm} is the predicted net energy required for maintenance, FFM_t is the predicted feed required for maintenance (dry matter), NE_g is the predicted net energy for gain, and WE_t is the equivalent weight (body weight adjusted by factors corresponding to breed frame codes, refer to Fox et al. (1988) for frame codes and adjustment factors) .

Since the profit of feedlots depends very much on the final quality of the meat products—the quality grade and yield grade in the context of a grid marketing system, we adopted the equations to predict the body composition, quality grade, and yield grade from Fox and Black (1984).

$$EBF_t = 100 * (0.037 EBW_t + 0.00054 EBW_t^2 - 0.61) / EBW_t$$

$$CF_t = 0.7 + 1.0815 EBF_t$$

$$QG_t = 3.55 + 0.23 CF_t$$

$$YG_t = -2.1 + 0.15 CF_t$$

where EBF_t is the percentage fact in the empty body, $EBW_t = 0.891 BW_t$ is the empty body weight, CF_t is the percentage fact in the carcass, and QG_t and YG_t are the quality grade and yield grade respectively. The QG_t values is related to the USDA standards as follows: Select^0=8; Select$^+$=9;Choice$^-$=10; et cetera.

While all of these equations predict the mean values of certain traits, the actual values may vary for a particular feeder. To get the expected discounts for the whole population of feeders under a grid marketing system, we must take into account of the trait variability. Follow Amer et al. (1994), the traits are modeled as random variables follow normal distributions (empirical distributions can also be used for better results) with mean predicted by the model and some estimated variances. The proportion of cattle marketed in a certain grid cell corresponds to the probability mass between the boundaries of the cell. The expected total discount/premium for cattle marketed after *t* days on feed can be calculated, denoted as Dis_t.

Now we have enough information to calculate the revenue, costs, and profit of the feedlot when the feeders are marketed at time *T*. The current value of selling the feeder at time T is given by

$$R_T = EP_T * CW_T * \exp(-r\frac{T}{365})$$

with R_T being the present valued revenue, EP_T being the expected price adjusted by the total expected discount Dis_T, and r being the discounting rate. The cost accrued at the slaughter point T includes ration cost and yardage cost

$$Ration_T = \sum_{t=0}^{T}(DMI_t * RC * \exp(-r\frac{t}{365}))$$

$$Yardage_T = \sum_{t=0}^{T}(0.25\exp(-r\frac{t}{365}))$$

where RC is the unit ration cost and yardage cost is assumed to be \$0.25 per day. The expected profit from one feeder is then given by

$$Profit_T = R_T - Ration_T - Yardage_T$$

Since the profit is only a function of the integer variable *T*, linear search within the domain of *T* could yield the optimal slaughter point and the maximum profit derived from the feeder. Let T^* be the solution to this problem, the corresponding finishing weight *FW*, finishing cost *AFC*, and expected discount *OptDis* are then used in the breeding decision process.

Meat Supply, Demand, and total Profit

The total supply of fed meat FMS_t is the number of feeders coming out of the feedlots multiplied by their finishing weight FW_t,

$$FMS_t = (1-d_1)FW_{t-1}(Fyg_{t-1} + Myg_{t-1}).$$

The supply of non-fed meat is determined by the number of culled breeding animal multiplied by the average slaughter weight ASW,

$$NFS_t = ASW\sum_{j=1}^{m}(1-d_j)a_{t-1}^{j}K_{t-1}^{j}.$$

For simplicity, we use single-equation constant elasticity demand equations for fed and non-fed beef. The mid-point own price elasticity ranges from 0.5 to 0.8 in the literature. We choose to use a value close to the average, 2/3 for fed beef. The demand for non-fed beef is usually less elastic, 0.5 is used in the non-fed beef demand. The two demand equations are

$$P_t = C_0 FMS_t^{-1.5} \quad \text{and} \quad SV_t = C_1(NFS_t \,/\, ASW)^{-2}$$

where C_0 and C_1 are two constant terms.

The revenue from fed meat is the market price minus the discount at the optimal slaughter weight multiplied by the total supply. The total feed cost FC_t is the average fed cost per feeder AFC_{t-1} (determined in last period) multiplied by the total number of feeders. The total breeding cost TBC_t is the average breeding cost ABC, which is assumed to be constant, multiplied by the total number of animals retained for breeding purpose. Total profit equals to the sum of the revenues from fed meat Rfm_t and from non-fed meat $Rnfm_t$ minus the feeding cost and total breeding cost. The equations are listed below,

$$Rfm_t = (Pm_t - OpDis_t) * FMS_t$$

$$Rnfm_t = SV_t * NFS_t \,/\, ASW$$

$$FC_t = AFC_{t-1} * (Fyg_{t-1} + Myg_{t-1})$$

$$TBC_t = ABC * \sum_{j=1}^{m} (1 - a_{t-1}^{j}) K_{t-1}^{j}$$

$$p_t = Rfm_t + Rnfm_t - FC_t - TBC_t .$$

Inventory Adjustment

Although rational expectations and bounded rational expectations have been used in beef production models trying to explain the cattle cycles (Rosen et al. 1994, and Aadland 2002) and they seem to perform well, using (bounded) rational expectations here has some disadvantages. First, analytical solutions of the profit maximization is necessary, which is a very demanding task if possible at all when the feedlot optimization is nested. Secondly, the full set of Kuhn-Tucker conditions need to be specified in the simulation model to handle possible corner solutions caused by severe IS outbreak. Thirdly and most importantly, obtaining the long-run equilibrium is crucial in solving the first order conditions, which is impractical when the producer has limited knowledge and great uncertainty of the effects of the IS on production.

In the case of beef production, naive expectations with partial adjustments may be better in describing the knowledge and resources available to the ranchers and their cautiousness when facing uncertainty. Breeding cows as capital assets, their capital value is not directly observable and the data on breeding cow trading is seldom available. However, the capital value of the cows is directly linked to their profitability, which is observable and can be easily obtained. Thus, naive expectation in unit profitability is used in the inventory updating policy.

Let $Reten_t$ be the number of heifers needed to replace the breeding cows that will die over the period and those at their end of productive life, it is given by

$$Reten_t = \frac{K_t^{10} + \sum_{j=1}^{9} d_j (1 - a_t^j) K_t^j}{(1 - d_0) K_t^0}.$$

When unit profit is zero, the expected marginal profit of increasing the breeding herd is zero. Only necessary replacement is needed to maintain the breeding herd size. When unit profit is positive, increasing the breeding herd would increase the total profit (competitive individual producers don't think their action can affect the market). The only way to increase the breeding herd is to retain more heifers than what's necessary for replacement

$$a_t^0 = (1 - Reten_t) + Reten_t (1 - \frac{2}{1 + e^{-p_t / BH_t}}) \qquad \text{if } p_t < 0 .$$

The culling rate for heifers is a decreasing function in unit profit, and it's lower bounded by 0 and upper bounded by 1 minus the retention rate. When the unit profit fall below zero, decreasing the breeding herd size will decrease the loss. To that end, the producer could retain fewer heifers than the replacement requirements and cull breeding cows as well.

$$a_t^j = (1 - \frac{2}{1 + e^{-p_t / BH_t}}) \quad \text{if } p_t < 0, \ = 0 \text{ otherwise } \ \forall j \text{ s.t. } 10 > j > 0$$

$$a_t^{10} = 1$$

$$a_t^0 = (1 - Reten_t) + (1 - Reten_t)(1 - \frac{2}{1 + e^{-p_t / BH_t}}) \ \text{ if } p_t > 0$$

This completes the specification of the simulation model of the beef production.

Calibration and Some Simulation Results

The death rate and birth rate are estimated from the cattle inventory data obtained from Production, Supply & Distributions Database, Foreign Agricultural

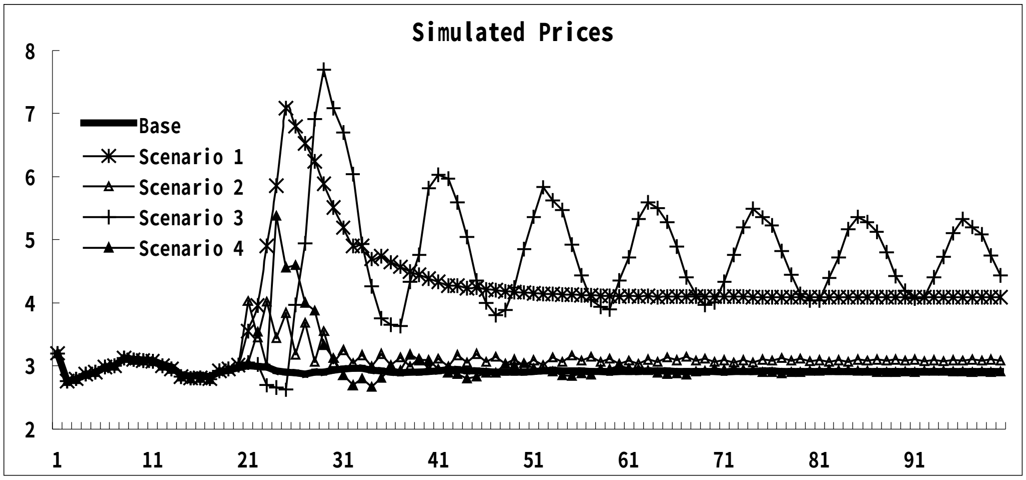
Services USDA. $d^j = 0.0457$ and $q = 0.85$. The ration we use consists of 70% corn, 25% alfalfa silage, and 5% soybean meal ($NE_{ma} = 2.03$ Mcal/kg and $NE_{ga} = 1.28$ Mcal/kg). The price of the ration is roughly $140/ton. Yardage cost is assumed to be $0.25/head/day. The economic interest rate is 0.09. The starting inventories are also estimated from cattle inventory data obtained from the PS&D database. The grid pricing system is presented in the following table

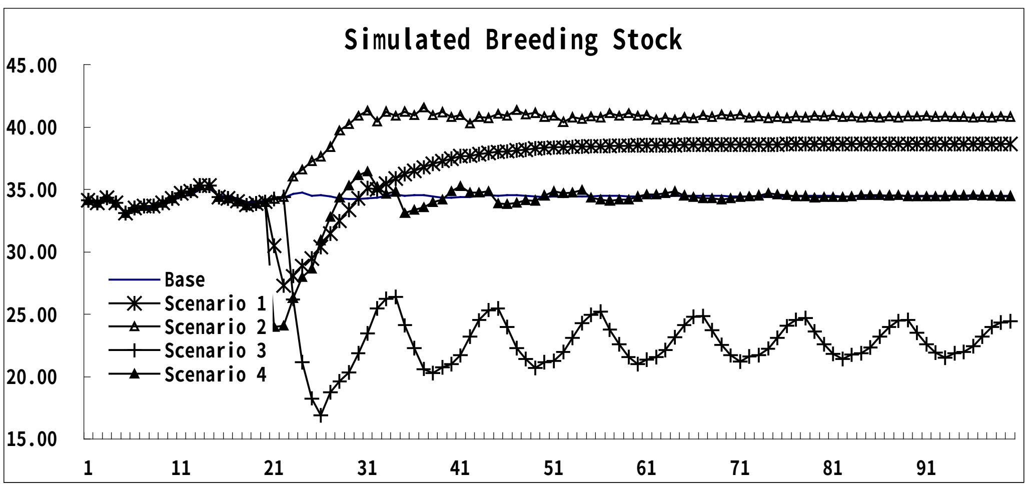
	YG1	YG2	YG3	YG4	YG5
Prime	10	9	8	-12	-17
Choice	2	1	0	-20	-25
Select	-5	-6	-7	-27	-32
Standard	-33	-34	-35	-55	-60
Out Cattle	<500	<550	>950	>1000	
Discount	30	10	10	30	

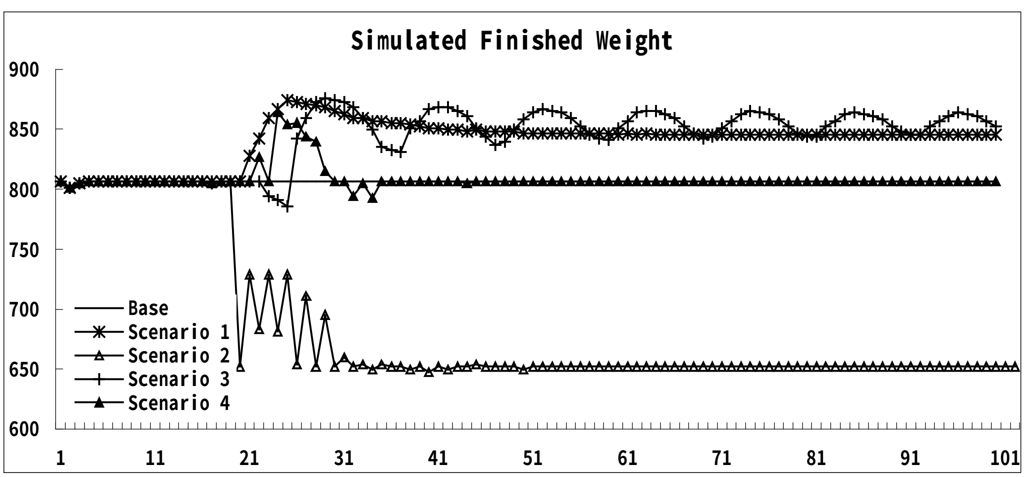
*values represent discounts/premiums for $100/CW

The standard deviation of carcass weight is assumed to be constant at 20 kg. The standard deviations of quality grade and yield grade are estimated using grading data obtained from Agricultural Marketing Service, USDA. They are 1.4 for quality grade and 0.8 for yield grade. The model is calibrated to the inventories and prices of year 2000.

A base scenario and four other scenarios representing different possible disastrous shocks that can be caused by an IS outbreak are run to check the validity and stability of the simulation model. The four scenarios include a permanent increase of death rate to 15%, a permanent 100% increase in ration cost, a permanent 100% increase in average breeding cost, and a one-time 30% decrease in all breeding inventories, corresponding to Scenario 1-4 respectively. The shocks start at the 20th period. The simulated results are graphed in the following charts.







As shown in these graphs, all of the permanent shocks change the equilibrium price, breeding stock, and finished weight to a new level. The one-time inventory shock doesn't change the equilibrium. In all four scenarios, wide fluctuations are observed at and shortly after when the shocks are introduce. The magnitude of the fluctuations gradually reduces as time goes by until the equilibriums are reached. Although in scenario 3, the permanent increase of average breeding cost generates persistence cycles, the cycles do have the tendency to die off. Under these dramatic shocks, the model successfully establishes the new equilibriums and gradually approaches them. These simulated scenarios verify the stability of the model.

The simulated results also make intuitive sense. In scenario 1, the 15% death rate reduces the current breeding herd size as well as the number of feeder, which creates a short supply of meat. The market price goes up. Although the production is less efficient due to the reduced output, the short supply creates a price so high because of the inelastic demand that it's still profitable to increase the breeding herd size. Building up the herd toward the new equilibrium level takes a long time because the replacement need is much higher and hence the ability to increase the herd size. The new equilibrium price is higher than the base, which reflects the lower output/input ratio. The new equilibrium breeding herd is higher than before but fewer feeders are produced. Feeders are relatively more valuable than the ration, so the feeders are fed longer. The total meat supply and consumption are reduced due to the shock.

In Scenario 2, the doubling of ration cost makes the feeders relatively cheaper. More feeders are produced and they are marketed at a earlier date to reduce the ration intake. Again, the higher cost results in a higher equilibrium price and total supply and consumption of meat go down. In Scenario 3, the 100% increase in average maintenance cost of the breeding animals makes the feeders relatively more expensive than other inputs. Thus, we have fewer breeding animals producing fewer feeders. And the feeders are marketed later to convert more feed into meat. In Scenario 4, the shock to the inventory is temporary. As expected, the temporary shock doesn't cause the equilibrium levels to change. It does cause fluctuations in production and consumption due to the nature of the population dynamics and the naive expectations. In three out of the four scenarios, the well-documented cattle cycle is observed—an indication that the model assumptions are valid.

Concluding Remarks

The livestock production relies on a breeding stock to produce new individuals that are used either for reproduction or as growing machines to generate meat. An accurate description of the life cycle and the biological characteristics of the breeding animals and the feeders are crucial for evaluating the economic effects of decisions or external impacts on various aspects of the production process. As indicated by the well-documented cattle cycles and hog cycles, population dynamics play an important role in livestock production. Follow Aadland, detailed age structure of the breeding stock is incorporated into the dynamic general equilibrium framework to more accurately capture the effects of an IS outbreak.

While most of the literature on IS focuses on evaluating the (potential) impact of a certain IS, we go further to establish the linkage between the (potential) loss and the risk of such loss and thus are able to do cost-benefit analysis of IS management policies. Furthermore, the linkage allow us to generate the optimal resource allocations among the multiple tiers and sites of an IS management scheme. By recognizing the fact that it could be rational to let a foreign species become endemic, the framework could also be used to identify if a foreign species should be classified as “invasive”, which makes it a useful tool in trade negotiation. The simulated scenarios of the beef production model indicate that simulation models based on the conceptual framework proposed make both economic and intuitive sense and the model is stable under dramatic shocks.

References

Aadland, D. (2002), “Cattle Cycles, Heterogeneous Expectations and the Age Distribution of Capital,” working paper, Department of Economics, Utah State University.

Amer, P. R., R. A. Kemp, J. G. Buchanan-Smith, G. C. Fox, and C. Smith. (1994) “ A Bioeconomic Model for Comparing Beef Cattle Genotypes at Their Optimal Economic Slaughter End Point.” *Journal of Animal Science*. Vol. 72, pp. 38-50.

Deaton, A. S. and J. Muellbauer (1980), “An Almost Ideal Demand System,” *American Economic Review*, Vol. 70, pp. 312-36.

Ekboir, J., Lowell S. Jarvis, and José E. Bervejillo, (2003), “Evaluating the Potential Impacts of a Foot-and-Mouth Disease Outbreak,” in Sumner, Eds., *Exotic Pests and Diseases: Biology and Economics for Biosecurity*. Iowa Sate Press, a Blackwell Publishing Company.

Fox, D. G. and J. R. Black. (1984) “A System for Predicting Body Composition and Performance of Growing Cattle.” *Journal of Animal Science*. Vol. 58, pp. 725-740.

Fox, D. G., C. J. Sniffen and J. D. O’Connor. (1988) “Adjusting Nutrient Requirements of Beef Cattle for Animal and Environmental Variations.” *Journal of Animal Science*. Vol. 66, pp. 1475-1495.

Grading Data (Quality & Yield). Agricultural Marketing Service, USDA.

http://www.ams.usda.gov/lsg/mgc/mgc-pubs.htm

Maguire, L. A. (2001), "What Can Decision Analysis Do for Invasive Species," Presented at the Workshop: Management Risk Assessment for Invasive Species: Perspectives from Theoretical Ecology, October 21-23 in Las Cruces, NM Department of Fishery and Wildlife Sciences, New Mexico State University.

Miller, W. (1979). " A State-Transition Model of Epidemic Foot and Mouth Disease." in McCauley et al., Eds., *A Study of the Potential Economic Impact of Foot and Mouth Disease in the United States.* University of Minnesota, APHIS-USDA.

Nutrient Requirements of Beef Cattle, National Research Council, 1996.

Production, Supply & Distributions Database, Foreign Agricultural Services, USDA. http://www.fas.usda.gov/psd/

Rosen, Sherwin, Kevin M. Murphy and Jose A. Scheinkman. (1994) "Cattle Cycles." *Journal of Political Economy*, Vol. 102, No. 3, pp. 468-492.