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Economic Impacts of Foreign Animal Disease

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Economic Impacts of Foreign Animal Disease

Philip L. Paarlberg, Ann Hillberg Seitzinger, John G. Lee, and Kenneth H. Mathews, Jr.

Abstract

This report presents a modeling framework in which epidemiological model results are integrated with an economic model of the U.S. agricultural sector to enable estimation of the economic impacts of outbreaks of foreign-source livestock diseases. To demonstrate the model, the study assessed results of a hypothetical outbreak of foot-and-mouth disease (FMD). The modeling framework includes effects of the FMD episode on all major agricultural products and assesses these effects on aggregate supply, demand, and trade over 16 quarters. Model results show a potential for large trade-related losses for beef, beef cattle, hogs, and pork, though relatively few animals are destroyed. The swine and pork sectors recover shortly after assumed export restrictions end, but effects on the beef and cattle sectors last longer due to the longer cattle production cycle. The best control strategies prove to be those that reduce the duration of the outbreak. While export embargoes lead to losses for many agricultural sectors, they also increase domestic supplies and lower prices, benefiting domestic consumers. Total losses to livestock-related enterprises over 16 quarters range between $2,773 million and $4,062 million, depending on disease intensity level, duration of the outbreak, and the response scenario. After seven quarters, production of all commodities returns to pre-disease levels in our hypothesized scenario.

Keywords: Animal disease, epidemiology, foot and mouth disease (FMD), sector model, trade

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Summary

This study uses a modeling framework to estimate the nature of economic impacts of outbreaks of foreign-source livestock diseases. The model is more comprehensive than previous work because (1) it has components for modeling both economic effects and disease-spread effects from an outbreak, for which the results can be integrated; (2) it assesses the effects of a disease outbreak on major agricultural sectors—livestock and crops—along vertical market chains, from production to consumption; and (3) it projects the impacts of the disease outbreak over 20 calendar quarters, rather than for just 1 year.

What Is the Issue?

As more is learned about the impacts of foreign animal disease outbreaks, questions arise regarding the efficacy of existing animal disease-impact models for capturing the array of effects across many economic sectors and over time. Previous models lacked adequate treatment of either the economic components or the epidemiological components, and, in some cases, both. Further, there is a need to address the ways that alternative control strategies affect the economic interests of the numerous agricultural sectors, both on and off the farm.

What Are the Major Findings?

While the framework can be applied to many livestock diseases, this study demonstrates the model with a hypothetical outbreak of foot-and-mouth disease (FMD). The outbreak is assumed to occur in small hog operations in the U.S. Midwest, a result of using contaminated garbage as feed. Various disease-control strategies are entered into the model. The economic effects from each control strategy are based on 50 iterations of the disease-outbreak epidemiological model, which randomly assigns different herd sizes, spatial distribution, and other variables for each iteration. The model produced the following key results:

- Epidemiological model results show that relatively few animals need to be destroyed because of the disease.
- Economic model results show large monetary losses for beef, beef cattle, hogs, and pork sectors, mainly caused by the loss of exports under a given set of foreign sanitary and phytosanitary policies. Other agricultural sectors experience small losses or, in some cases, small gains.
- Swine and pork sectors recover shortly after export restrictions end, while effects on beef and cattle sectors last longer due to the longer cattle production cycle.
- Disease control strategies that reduce the duration of the outbreak are the most effective choices for reducing the economic toll. The model found that three strategies reduce the duration to less than one quarter. In order of least to most effective, based on the mean number of days to end the outbreak, for the hypothetical outbreak these are:

- Destruction of only those herds within a radius of 1 km that have had direct contact with infected herds: Outbreaks average 56.48 days.
- Direct-and-indirect-contact slaughter, which destroys direct-contact herds plus those herds indirectly exposed to an infected herd through movement of people, vehicles, or other possible sources of infection: Outbreaks average 54.99 days.
- Destruction of all herds within a 1 km radius of the initial outbreak: Outbreaks average 36.8 days.

• Export embargoes increase domestic meat supplies, and domestic consumers benefit from lower prices during the quarters in which exports are embargoed.

• Model results, extended to 16 quarters, show that for this hypothetical outbreak:

- After 7 quarters, production of all commodities increases to the point where both domestic consumption and trade return to pre-disease levels.
- Total trade losses, plus other disease-related costs to capital and management, amount to between $2,773 million and $4,062 million, compared with a disease-free baseline period (2001-2004).

***How Was the Study Conducted*?**

The framework has two components: (1) The North American Animal Disease-spread Model (NAADSM), developed by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service, which enables estimates of epidemiological damages (supply shocks) from varying disease-spread and control scenarios. These estimates can then be integrated with (2) an economic model, developed by Paarlberg, Seitzinger, and Lee, that assesses effects of supply shocks from the epidemiological model, along with demand and trade shocks, projected over the simulation period.

To illustrate the modeling framework, a hypothetical outbreak of FMD arising from feeding garbage in four small farrow-to-finish operations is examined under three alternative control strategies and three levels of disease intensity. The control strategies are (1) destruction of direct-contact herds, (2) destruction of direct-contact and indirect-contact herds, and (3) destruction of all animals within a 1-km ring. Disease intensity is examined at low, medium, and high levels. Each disease control scenario was simulated 50 times, with the epidemiological model determining effects of an outbreak.

Animal losses and duration of the FMD outbreak are sensitive to the conditions assumed for the outbreak, i.e., that it started on small pig farms and was confined to them. Alternative scenarios could result in higher costs than reported in this analysis. Future work will evaluate the robustness of these results.

Introduction

Eradication of diseases from the U.S. livestock and poultry population has a long history, including declarations of freedom from contagious bovine pleuropneumonia in 1892, foot-and-mouth disease (FMD) in 1929, screwworm in 1959, and hog cholera in 1978, and we are now on the verge of eradicating brucellosis, tuberculosis, and pseudorabies (Dunlop and Williams). Many factors determine which diseases warrant eradication. Chief among them are concerns about human health, impact on livestock productivity, and restrictions imposed by importing countries on exports of U.S. livestock and livestock products due to the presence of disease (Wiser).

However, the eradication of so many diseases does not allow the United States to declare victory in the battle for livestock and poultry health. The competitiveness of U.S. livestock and poultry in domestic and international markets is constantly threatened by diseases in North America—both known and newly emerging and foreign and endemic—such as Bovine Spongiform Encephalopathy (BSE or Mad Cow Disease). Costs of just monitoring and surveillance programs for livestock diseases alone, estimated for the 2006 Animal Health Monitoring Systems budget at almost $150 million per year, are significant.

Cost/Benefit Analyses

Some earlier studies have done cost/benefit analyses for U.S. programs aimed at preventing or mitigating impacts of livestock diseases. Their conclusions point up the potential impacts of these diseases and the relatively limited costs of eliminating them. Discounted benefits to the United States of the screwworm program, which ran from 1958 to 1986, are estimated at $2.8 billion, compared with discounted eradication costs of $240 million (USDA/APHIS). For hog cholera, the 16-year eradication program (1961-1976) was estimated to generate $2.9 billion in benefits at a cost of $140 million (Wise). Estimates of the brucellosis eradication program (1985-2005) show an $18.3-billion gain in producer and consumer surplus as a result of the program (Dietrich, Amosson, and Crawford, 1987).

Other analyses reinforce the value of eradicating diseases, such as FMD, by estimating their impact should they reenter the U.S. livestock population. The potential losses from an FMD outbreak in California are estimated to range between $8.5 and $13.5 billion (Ekboir). A substantial share of those estimated losses, $6 billion, is attributed to an embargo on U.S. meat exports. Paarlberg, Lee, and Seitzinger (2002) estimate that an FMD outbreak similar to the one that occurred in the United Kingdom during 2001 could generate U.S. farm income losses of $14 billion. They estimate individual sector losses, measured from a no-disease baseline, as 34 percent for live swine, 24 percent for live lambs and sheep, 10 percent for lamb and sheep meat, 15 percent for forage, and 7 percent for soybean meal,

Paarlberg, Lee, and Seitzinger (2002) estimate that if only 7 percent of U.S. consumers react to an FMD outbreak by cutting meat consumption (i.e., in the mistaken belief that FMD causes human health problems), the national welfare losses from the outbreak would be more than double the amount of losses with no such response. However, in a later study, the same authors

(2003) demonstrate that—despite aggregate welfare losses—there are groups of both producers and consumers who can potentially make welfare gains during a disease outbreak. For example, producers who were able to sell cattle for beef benefited from higher prices.

Model-Based Research

The economic impacts of selected livestock and poultry diseases are determined by translating epidemiological impacts of the disease into the appropriate shifts in supply. The supply shifts are generated from estimates of disease prevalence found in the literature, as well as from results of the epidemiological disease-spread model, NAADSM (Harvey et al.). The results for each disease under alternative control simulations, such as ring slaughter within a radius of 1 km, are introduced into a U.S. agricultural sector model—along with information about trade impacts, regulatory costs, and potential consumer reactions—to determine the impacts on market prices, quantities, and the welfare of economic decisionmakers. The economic interests of those on and off the farm are affected somewhat differently by alternative control strategies.

A number of studies have used combined epidemiologic-economic frameworks. Ekboir (1999) uses an epidemiological model for an FMD outbreak in California dairy cattle as input into an input-output model for that State. McCauley et al. (1979) determined the potential impacts of a hypothetical FMD outbreak in the United States and the costs of alternative control strategies. Berentsen, Dijkhuizen, and Oskam (1992) and Dijkhuizen, Renkema, and Stelwagen (1991) examine a potential Dutch outbreak of FMD. Rendleman and Spinelli (1994) use a national simulation model to analyze the economic impacts of an outbreak of African swine fever in the United States. Petry, Paarlberg, and Lee (1999) estimate the adverse impacts of porcine respiratory and reproductive syndrome (PRRS) on U.S. swine trade with Mexico. Zhao, Wahl, and Marsh (2006) present an analysis of an FMD outbreak on the U.S. beef sector that integrates an epidemiological model with an annual dynamic model of the beef and beef cattle sectors. Seitzinger, Paarlberg, and Lee (2006) use a similar framework in analyzing the effects of a scrapie outbreak.

This previous research quantifies the economic impacts of selected livestock and poultry diseases that pose a threat to the competitiveness of U.S. livestock and poultry and the products derived from them. The studies focus on the economic effects of consumer and international trade responses to the presence of livestock diseases and alternative disease control strategies. However, the framework in our study extends previous work in two ways: it includes the major agricultural products along vertical market chains from livestock products to animal agriculture and crops, and it has the capacity to follow the effects over 20 quarters (see also Paarlberg, Seitzinger, and Lee, 2007).

The next section presents a conceptual model that integrates components from economic and disease-spread modeling frameworks. FMD is chosen to illustrate disease impacts because it is among the most common foreign animal diseases and has an extensive body of research from which to extract disease-spread parameters needed for the framework.

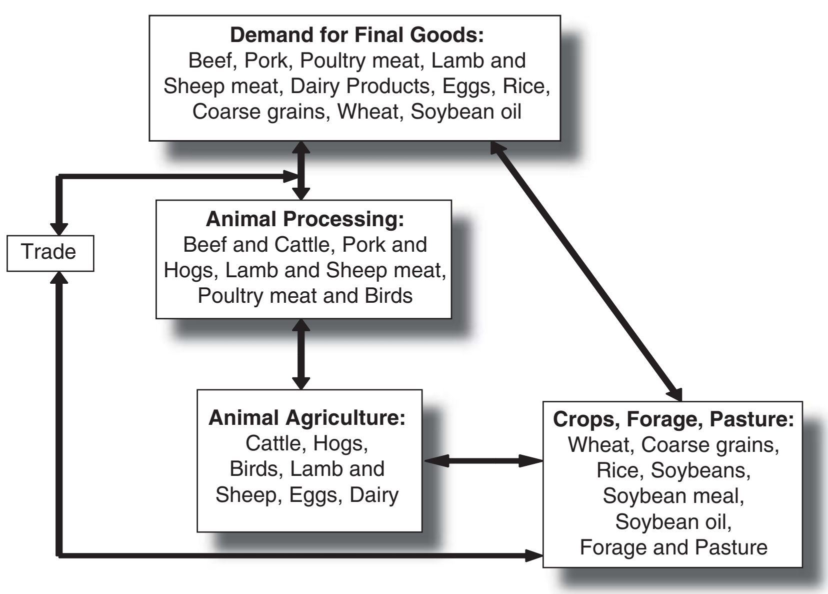
A Conceptual Model of the Agricultural Sector

Efficient modeling of the impacts of FMD in the United States is enhanced by integrating a disease-spread model with an economic model. For building a quarterly agricultural model, a general plan is required for the model's structure and for how the pieces fit together (fig. 1). A detailed presentation of the model is found in appendix A. The general approach follows that of Jones (1981) and Sanyal and Jones (1982).

The model and application assume price-taking economic decisionmakers who maximize well-defined objective functions. Utility maximization for consumers gives a set of per capita demand functions. Producers (firms or farms) choose inputs and products that maximize profits using four types of inputs. One type, which includes fuel and electricity, is mobile among production activities and is in perfectly elastic supply. A second set of inputs consists of sector-specific intermediate goods. A third input type consists of sector-specific physical and human capital, and the final input is land, which is mobile across crop production.

Total consumption of final goods (beef, pork, poultry meat, lamb and sheep meat, eggs, milk, wheat, coarse grains, rice, and soybean oil) in the U.S. economy in the current quarter depends on population and per capita consumption during the quarter. Wheat and coarse grains are included, since they are also used for feed. Soybean oil is included because its joint product, soybean meal, is a major feedstuff. Rice is modeled because its area interacts with crops used for animal feed. Health-shock parameters are incorporated that allow variations in the level of consumer perception of health risks.

Figure 1
Economic modeling component for analyzing effects of foreign animal diseases on U.S. agricultural sectors



Source: Compiled by the authors.

These parameters indicate the share of the population unafraid of a health risk associated with each final good and provide a policy instrument by which to manage policy impacts on final demand.

Goods (meats, eggs, milk, animals, and crops) are produced by separate industries (sectors). Firms producing individual meats do not earn supernormal profits, so a zero-profit condition holds for each meat, as well as for milk and eggs. Production of meats, eggs, and milk is assumed to occur during the current quarter, while production of animals and crops are lagged according to biological limitations. Three types of production factors are used: factors in perfectly elastic supply, animal intermediate inputs (livestock and poultry), and sector-specific primary factors (physical and human capital). Markets clear at market prices, determined by market-clearing identities that are consistent across time, with biological lags.

Livestock

Livestock are described here as a primary output, but also act as intermediate inputs into meat production. From this point, poultry may be included as livestock or animals and will only be listed or mentioned separately when it is necessary to discuss it separately. Breeding and replacement decisions reflect previous livestock inventories, salvage values, and the expected relative profitability of producing animals or products for future sale. During a disease outbreak, these inventories (and values) are adjusted to reflect disease-induced losses.

Four types of feed are available in the model: wheat, coarse grains, soybean meal, and forage and pasture. Not all livestock use all feeds, and each growth stage has unique derived (input) demands for feed. Use of a feed ingredient is a function of the feed prices and the number of animals consuming feed in each stage. The model reflects the fact that cattle, hogs, sheep, and lambs have production cycles spanning more than one quarter.

The structure of the dairy sector and its feed allocation differ from sectors with other livestock species because the model determines milk production using the zero-profit and specific factor-market-clearing conditions. Milk output and dairy cattle being milked are determined simultaneously. The decision to determine milk output directly and convert that output into dairy cows reflects the way cost data are reported: Production costs for milk include the feed costs, but not the cost of replacement heifers, whereas meat cost data include the animal, but not the feed. Disease outbreaks are reflected in reduced milk output, which translates into reduced dairy cattle inventory. Thus, the size of the dairy herd in the quarter is determined by milk output in the current quarter and, because inventories of dairy cattle are slow to adjust, by lagged dairy cow inventory.

Due to their short production cycle, poultry stocks are relatively simple to model, with the number killed determined in the current quarter using zero-profit and specific factor-market-clearing conditions, but also influenced by output lagged by one quarter. The model determines egg production, using the zero-profit and specific factor-market-clearing conditions. The number of layers and the feed use is known from egg production. Disease affects egg production (and thus layer numbers). Layer stocks respond more slowly than broilers, so lagged production is included with a stronger effect.

Trade is linked to U.S. market prices, trade policy, and disease outbreaks. Trade policy intervention is modeled as a specific trade intervention during the current quarter, with trade determined by the U.S. domestic price less the specific trade intervention. Because an animal disease outbreak can disrupt trade, parameters are used to indicate the severity of trade restrictions.

Crops

The foregoing discussion identified intermediate demands for crops as feedstuffs. In addition, there are final (retail) demands for crops. Crops included in the model are wheat, coarse grains, soybeans, rice, and forage and pasture. Focusing on the supply side, crop production occurs at set times and then becomes carryin stocks in subsequent quarters until a new crop is harvested. Crop supplies in a given quarter are any crops produced in that quarter, plus any carryin stocks. Another key feature is that production decisions are made well before harvest, based on expectations of crop returns. Finally, except for forage and pasture, all of the crops included in the model are program crops. This means the influence of the various U.S. Government price and income supports must be incorporated. Acreage allocations are based on expected net returns for each crop at harvest, with expected returns being the previous harvest prices plus appropriate government payments. The computations are done in quarter 1 so that acreage allocations consistent with one crop cycle can be imposed. Since there are both winter and spring crops in the model, this is a simplification of the actual decision process. Soybeans and rice are spring crops (planted in the second quarter of the current year and harvested in quarters 3 (rice) or 4 (soybeans). Coarse grains (corn, sorghum, millet, barley, rye, and oats) are planted in quarter 2 and harvested in quarters 3 and 4. Barley is planted in both winter and spring and is assumed to be harvested in quarters 2 and 3.

Wheat pose a larger problem because it is a major crop, like corn and sorghum, but with both spring and winter crops. Spring wheat is planted in quarter 2 and harvested in quarter 3. Winter wheat is planted in the fourth quarter of the previous year and is assumed to be harvested in quarter 2. The acreage (production) decision for that second-quarter harvest is assumed to be made in the first quarter of the year and is based on returns to second-quarter wheat in the previous year. This is done to create a consistent use of land, because it requires arranging inputs earlier in the year and constrains cropping decisions in the spring.

Forage and pasture pose problems similar to those of wheat. Production occurs in quarters 2 and 3. Forage and pasture acreage is assumed to be determined in quarter 1, based on the prices in quarters 2 and 3 of the previous year.

The economic return to land captures the negotiation process between farmer and landlord for land rent for the upcoming crop season. Land is mobile among crops. The expected return to land is determined by the land-market-clearing condition and the expected zero-profit conditions for each crop, which include the costs of exogenous factors and the expected return to physical and human capital for each crop, as determined by the expected return for the crop. Expected returns for crops vary with market conditions. The price expected in quarter 1 is the price prevailing in the harvest quarter of the previous year. The returns also reflect U.S. Government payments, of which there are several. There is some debate about how they affect production, for example, because of the decoupling issue (Goodwin and Mishra, 2006).

In our model, the farmer is assumed to receive loan deficiency payments (LDPs) equal to the difference between the loan rate (LR) and market price when the LR exceeds the quarterly market price. Payments are made on the full amount of production. Direct payment rates (DPs) are established in law. Total payments are the rate multiplied by 85 percent multiplied by program yield and base area. Additionally, the 2002 Farm Act provides for counter-cyclical payments (CCPs) calculated from an announced target price (TP). The payment rate is the difference between the target price, less any direct payment, and the market price when the market price is above the loan rate. If LDPs are paid, they are not adjusted by the 85 percent used in the CCP adjustment, but instead, the full LDP is added to the market price. The CCP payments are 85 percent of the crop base acreage times program yield times the payment rate. The expected return is the expected price on the previous crop plus CCP payments, LDPs, and direct payments.

Loan deficiency payments are coupled payments. A critical issue is whether direct payments and CCPs are decoupled or not. Returns to human and physical capital and to land cannot be adequately modeled without including these payments, so they are reflected in the model and affect the dynamics of the model solutions. The payments are modeled to affect relative per acre returns among program crops. Since forage and pasture are not program crops, there is no direct price adjustment, but there is a relative price effect.

Sector-specific, factor-market-clearing conditions, using expected rent and factor prices in quarter 1, determine crop output for the harvest quarter. Land is mobile among the crops. Its return is determined in quarter 1 by the demand and supply for land for the upcoming crops in period t. While crop output is determined based on the expected returns to sector-specific factors, actual returns to the sector-specific factors can differ from expected returns because actual returns to crop production differ from expected returns. The actual market prices are determined in market-clearing identity equations. Once the crop-market prices are known, the LDP and CCP payment rates and total payments can be calculated for the crop produced at time t. The actual return to the program crop is arrived at with the addition of the payments. The return to forage and pasture is the market price, since there is no program.

The soybean complex is included because soybean meal is a major feedstuff whose use is affected by any disease outbreak, and soybeans compete with other crops for acreage. In addition to soybeans as a crop, there are demands for soybean meal in animal feed and soybean oil for human food. Thus, soybean processing, or crushing, into the joint products of meal and oil, must be modeled. This is done by specifying a derived demand for soybeans for crushing as a function of the current-period crushing margin. The crushing margin is the value of the joint-product yields multiplied by their prices and adjusted for the price of soybeans.

Closure

Model closure requires domestic and international market-clearing relationships for quantities and prices. Exports depend on prices and trade interventions and, in some cases, on the disease outbreak. For many agricultural goods, the United States is an exporter and does not intervene in the market. While many agricultural goods are imported into the United States without restriction, beef and dairy products are subject to tariff-rate quotas, TRQs. A TRQ is a stepped tariff, with import volumes below the quota requiring payment of a lower tariff than volumes above the quota. To facilitate a model solution, it is assumed that the quotas are not filled and that the below-quota interventions apply. Quota underfill seems to be more common for U.S. beef imports than quota overfill. When an intervention is applied, it is deducted from the U.S. domestic price, so that trade reacts to the "world" or border price. The remaining imports are explained by an excess supply to the United States.

Completing the model requires vertically linking farm prices for crops and livestock, wholesale prices for meats, milk, and eggs, and retail prices for all final goods. These three levels are linked by calculated marketing margins. This vertical linkage improves the numerical accounting of the impacts, but does not affect the model response to shocks.

Differential Transformation of the Conceptual Model

A numerical solution of the integrated economic agricultural sector model is facilitated by a total logarithmic differential version of the model described above, for which the details are presented in appendix A. The logarithmic-differential version has several advantages: (1) the differential version is driven by elasticities, which are easier to obtain than specific functional forms and are also more intuitive than partial derivatives; (2) the elasticity version can be applied to observed historical data, which avoids the need to forecast future exogenous variable values; and (3) the base data can be updated quickly as new values become available. While we give a brief description in the following paragraphs, details of the conversion of the conceptual model to the total logarithmic differential version are found in appendix A.

Meat, milk, and egg production are described by the zero-profit equations and the sector-specific, factor-market-clearing conditions. After totally differentiating the zero-profit conditions at time t, applying the envelope property, and normalizing quantity on the unit isoquant, the percentage change in the wholesale price becomes a linear combination of the factor-price changes. With the mobile factor price exogenous, the mobile factor-market-clearing identity is dropped so the sector-specific, factor-market-clearing conditions can be partitioned into two sets of equations: (1) the per unit use of physical and human capital and (2) the derived demand for animals for beef cattle, swine, lambs, sheep, and poultry slaughter and for dairy-cow and poultry-layer production inventories.

Completing this part of the model requires specifying the changes in per unit factor uses. This is accomplished with a matrix of Morishima elasticities of substitution (e.g., Chambers, 1988, p. 96) between mobile factors and capital, and between animals and capital, under constant returns to scale. Logarithmic differentiation links changes in the ratio of per unit factor use to changes in factor prices, via the Morishima elasticities of substitution.

The feed demands reflect the age distribution and flow of animals. Because the per unit feed demands are responsive to changes in relative feed prices, the percentage changes in the derived demands for feeds also use Morishima elasticities of substitution between each feedstuff and each category of each species of feed-consuming livestock. Changes in relative prices alter the per animal mix of feedstuffs according to the Morishima elasticities of substitution.

The next component of the model consists of logarithmic differentiation of the crop production structure to determine changes in expected net returns for each crop and changes in production of each crop, including changes in land allocations. Changes in production of each crop, including changes in land allocations, determine land rent. Soybean crushing depends on the margin, which, in turn, depends on the prices of soybean meal, soybean oil, and soybeans. With assumed constant meal and oil yields, differentiating the crush demand and the margin identity gives changes in supplies of meal and oil.

Closure requires logarithmically differentiating excess demand, excess supply, and commodity-market-clearing conditions. The excess-demand and excess-supply equations include trade policy interventions. Since several commodities do not have trade interventions, the logarithmic change is not defined. Thus, trade policy interventions are treated as specific (per unit) policies, and the differential form differs from the other equations. In addition, each commodity has a market-clearing condition in which the total differential includes derived demands for animals and feed ingredients and maintains the linkages through the total differentials of the margin-markup equations.

Simulation of an Outbreak of Foot-and-Mouth Disease

This section provides a general description of the inputs to the numerical model. At a broad level, two sets of information, data and parameters, are required. These are detailed in appendix B.

Data

Most of the data required for the model consist of quarterly supply, use, and price figures for the years 2001-04. These values set the baseline to which the percent changes are applied. With some exceptions, the data are reported in the Livestock Marketing Information Center (LMIC) database. The LMIC database does not include some data for crops and trade. Quarterly supply, use, and price data for coarse grains, wheat, and rice come from situation reports prepared by the Economic Research Service of the U.S. Department of Agriculture (USDA/ERS, Outlook series). Quarterly supply and use tables for the soybean complex prepared by ERS cover the later years, but not 2001. The missing values for 2001 are generated using the newer data and assumptions about use patterns. In some cases, monthly data are summed or averaged to generate quarterly data.

Forage and pasture data are difficult to obtain. Forage prices are from the LMIC database. Total quarterly use is generated by feed balance spreadsheets, in which data on animal numbers are combined with standard feeding practices to produce quarterly amounts fed of forage and pasture. Production data are limited. Production of hay, corn silage, and sorghum silage is reported by the National Agricultural Statistics Service, U.S. Department of Agriculture (USDA/NASS). No recent data exist for uncut grazed pasture. While there is some early forage harvest, there is no way to find out how much of the forage is harvested in the second quarter of the year. The assumption in this model is that forage harvest occurs in the third quarter. Given the quarterly use and third-quarter production, the residual is treated as grazed pasture. This residual is allocated equally to quarters 2 and 3, with no forage and pasture production in quarters 1 and 4. With this information, quarterly supply and use are calculated so that no quarter from 2001 through 2004 shows a negative carryover.

While LMIC and ERS report aggregate trade data for animals, the model requires decomposing those data into animals for slaughter and those to be fed. The data are obtained originally from U.S. Customs through the Foreign Agricultural Service, U.S. Department of Agriculture (USDA/FAS).

Policy information affecting crop variables comes from various sources. Policy data for 2001 and 2002 are reported by Nelson and Schertz (1996) in *Provisions of the Federal Agriculture Improvement and Reform Act of 1996*. Policy data for the 2002 Farm Act are taken from the Outlook reports prepared by ERS for rice, wheat, feed grains, oilseeds, and oilseed products (USDA/ERS Outlook series).

Parameters

Four sets of parameters drive the model: the livestock feed-balance calculator, the revenue shares for all industries, elasticities used in model solution, and disease-related parameters used to manipulate disease scenarios. The numerical model is constructed so that the user can alter the parameter values. This is useful because there is no consensus in the literature for many parameter values. The first three sets of parameters discussed here are based on estimates in the literature, tempered in some cases by the authors' judgments. Animal disease parameters, the fourth set, are discussed below in the "Disease and Disease Control Impacts" section.

Livestock-Feed Balance

The livestock-feed balance calculators are critical because they relate the stocks and flow of animals for each quarter to the feed supplies available, forming the vertical linkage between the animal agriculture and crop components. The first step in determining animal feed consumption is to formulate typical animal diets for each weight class or other category for each species of livestock and poultry. For example, rations are formulated for hogs in weight ranges of 10-59 pounds, 60-119 pounds, 120-179 pounds, and 180+ pounds. The next step is to determine weight gain and feed consumption by animals in each weight category (phase of production). By entering the beginning and ending weight in each phase, the model calculates the total weight gain and tracks how much feed is consumed for this weight gain. For example, a pig must consume a total of 92 lbs of feed to reach 60 lbs. The calculations assume an average feed efficiency, or feed consumed per unit of weight gained, and are scaled to reflect the greater efficiency of lighter animals compared with heavier animals. Average daily gains are used to calculate how many days each animal spends in each phase. Using these calculations, we can obtain the total number of days for an animal to reach market age.

Next are the percentages of feed grains, wheat, soybean meal, and premixes/other feed ingredients in the diet for each phase of production. Knowing the percentage of each ration for each phase allows calculation of the total and daily feedstuffs consumed. Mortality rates for each phase of the production process are used to calculate total deaths during production. Consumption patterns are produced by tracking inventories, which are used to calculate quarterly feed use. Consumption by foreign-born animals must also be recognized; assumptions are made about the weight (age) of animals entering the United States. In some cases, annual quantities are allocated to quarterly consumption by dividing by 4, with no seasonal adjustments. Calculation of layer feed consumption is calculated directly from the USDA average monthly layer number and average daily layer consumption (Leeson and Summers, 1997, 2001), and the percentages of that consumption that are the specific feed ingredients. Feed consumption by market-bound poultry is based on the total pounds of slaughter, estimated feed conversion, and percentage breakdown of each feed component in the poultry ration.

Revenue and Factor Shares

Revenue shares appear in the logarithmic-differential-equation form of the zero-profit conditions (appendix tables 1-6). Factor shares appear in the logarithmic-differential-equation form of the land-market-clearing identity. Cost-of-production data for corn, wheat, soybeans, rice, hogs, cattle, and milk are divided by production revenue to find the revenue shares. Crop revenue includes U.S. Government payments, since they are necessary for land, capital, and management to show positive returns. In general, crops show fairly even allocations among exogenous inputs, land, and the residual cost of capital and management. For live animals, the major revenue share is allocated to feed costs, followed by the residual return to capital and management. Milk is an exception that reflects the way the data are reported. In the case of milk, the animal value is implicit because the milk costs include feed and veterinary costs. Thus, the large residual to capital and management includes the capital value of the dairy cow. The remaining revenue shares come from a variety of sources.

In general, meat industries show low residual returns to capital and management because the bulk of revenue is allocated to animal costs. The exceptions are poultry meat and eggs, treated as vertically integrated industries, with firms capturing the difference between meat and egg sales and feed costs. Thus, the value of the animal is implicit, and the firms capture a large residual return to capital and management. The revenue shares for the individual feed ingredients are calculated from the livestock-feed balances that determine feed use for individual feeds, based on animal numbers. This allows the per animal feed use, by feed by animal type, to be calculated. Land factor shares are also calculated with data from a variety of sources.

Elasticities

Elasticities from several studies are critical parameters and are grouped into several sets. Most own- and cross-price elasticities of retail demand are based on estimates from econometric models (appendix table 7). Cross-price elasticities are non-negative, implying that the commodities involved are substitutes and are small, which affects how the model reacts to disease outbreaks that alter prices. There are some cross-price effects in meats, but few elsewhere. Price flexibilities for meats, estimated by Holt (2002), are converted to elasticities using matrix inversion. In contrast to the more familiar inelastic annual estimates, these values are elastic and indicate the willingness of consumers to alter purchases in response to shortrun price changes.

Substitution elasticities describe derived demand behaviors and affect supplies of the output commodities in the equation from which they are derived (appendix tables 8, 9, and 10). The original substitution elasticities for the meats are estimates from MacDonald and Ollinger (2000, 2001). Model solutions evaluated by individuals with experience in meatpacking were viewed as having excessive meat-yield changes as capital substituted for animals. Thus, in the model, the values from MacDonald and Ollinger were lowered to reduce meat-yield changes. The substitution elasticities for feed use are generated with a technique used by McKinzie, Paarlberg, and Huerta (1986) that requires developing least-cost feed rations by animal species. Some substitution elasticities were not found in the literature, so values consistent with commonly accepted supply elasticity values are used.

A number of elasticities tied to animal agriculture inventories are econometrically estimated as part of the study (appendix table 11). Exceptions include bird numbers, tied directly to poultry meat and egg outputs with elasticities of 1, and milk production and dairy cow numbers.

International trade elasticities were difficult to obtain in many cases since, despite decades of research, there is little consensus about the magnitudes. Further, for the model to behave correctly for livestock disease issues, intra-sector trade must be modeled. This is done by inserting both excess demand and excess supply functions, either from a variety of sources or by assuming them to be either 0 or 1, with some exceptions.

Finding ending stocks elasticities proved difficult, since these values are rarely reported in the current literature. Older studies did include ending stock estimates for crops. Experimenting with model solutions produced a set of elasticities that gave reasonable behavioral responses (appendix table 13). The remaining ending stocks are treated as residuals in the model solution. Stocks for these commodities are generally small relative to use, and some commodities like soybean meal are difficult to store. Thus, ending stocks for such commodities are treated mostly as transaction or pipeline stocks. The results of model solutions show small percentage changes.

Disease and Disease-Control Impacts

The agricultural sector model described above is designed to link to the North American Animal Disease-Spread Model (NAADSM) (Harvey et al.) to determine control responses to disease in terms of impacts on economic decisionmakers. Simulations in NAADSM are initiated by describing the susceptible population within which the outbreak occurs. This can include any number and type of subpopulations (e.g., dairy cattle, beef cattle, intensively raised pigs, and pastured sheep). Description of the population includes the size of individual herds or flocks and their spatial location within the simulation region. The size of this region and the density of herds or flocks can be altered, and clusters within the region can be created.

Once the population and a simulation region have been defined, NAADSM asks for a series of epidemiological and intervention cost parameters. Epidemiological parameters include factors associated with disease transmission and with relevant human interventions. Intervention parameters include the costs of implementing quarantines and surveillance zones, as well as the costs of herd removal and vaccination.

NAADSM uses daily time steps, after which the infection state of each herd is revised according to the outcome of the probabilistic events and interventions that have taken place during that step. The system updates the database, and the next daily time step is simulated. At the discretion of the user, the process is repeated until: (a) the first case is detected; (b) the outbreak has run for a given number of days; or (c) the outbreak has ended. This constitutes a single iteration of the stochastic process. At the discretion of the user, the outbreak scenario is rerun over a given number of iterations to create simulation outputs in the form of probability distributions. Outputs generated by the disease-spread model include epidemiologic statistics (infection statistics, intervention statistics, and GIS data) and the government costs of the interventions. These outputs are entered as supply shocks into the agricultural sector model on a quarterly basis.

Scenarios

A hypothetical outbreak of FMD in the United States is used to illustrate the use of the combined NAADSM and economic modeling system. This section describes the scenarios and the results they generate from the NAADSM. These results are inserted into the quarterly U.S. agricultural sector model, and the model solutions are presented.

Understanding the scenario introduced into NAADSM is critical because the results of that model are sensitive to the number of initial FMD cases, the vector of introduction, the type of operation in which the disease appears, and the geographic location of the disease. In this hypothetical example, initial cases of FMD occur at the beginning of a quarter as a result of contaminated garbage used as feed in four small farrow-to-finish swine operations. Because small swine operations are more likely to feed garbage and garbage is a likely vector of transmission, the outbreak starts in this kind of setup.

The operations are small, with few animals initially infected. Off-farm movements are also small, so the most important vector for spreading the disease is airborne transmission. The outbreak occurs in a region of the U.S. Midwest where swine are the dominant livestock, followed by dairy cattle. Beef cattle operations are less common in the region, and there are no large feedlots. Sheep raising is also uncommon in the simulation region.

Three alternative control strategies are considered. For each control strategy, NAADSM is solved for 50 iterations, and the low-, medium-, and high-destruction outcomes from these 50 iterations are used in the agricultural sector model to evaluate the range of economic impacts. The strategies are:

- Direct-contact slaughter, which destroys only herds having direct contact with infected herds. For example, a herd next door to an infected herd or one receiving animals from an infected herd would be destroyed.

- Direct- and indirect-contact slaughter, a more aggressive control strategy, which destroys direct-contact herds plus those herds indirectly exposed to an infected herd through movement of people, vehicles, or other fomites (inanimate objects that can transmit infectious organisms), to account for off-farm animal movement. A key parameter in this strategy is the ability to successfully trace animal movements through the marketing chain. For these scenarios the tracing success rate in NAADSM is set at 50 percent.

- Destruction of all herds within a 1 km ring, which is very effective in controlling the outbreak. Larger rings of 3 and 5 km were analyzed, but the length of the outbreak and the number of animals destroyed was not much different from the 1-km ring slaughter.

Epidemiological Results

The low-, medium-, and high-NAADSM results for the three control strategies are shown in table 14. The maximum number of animals killed is 77,582 out of a susceptible population of 9.8 million animals. This reflects the assumption that the four initial cases appear in small swine operations with few off-farm animal movements. Animal destruction reflects the relative importance of the number of animals in the proximity of initial outbreaks and of the number of initial cases appearing on small hog farms. Slaughter swine for market constitute the largest category of animals destroyed, followed by breeding swine. Dairy cattle are consistently destroyed, but not in great numbers. Beef cattle for market and for breeding are destroyed under the mean- and high-destruction outcomes, but not in the low-destruction outcomes. Even when beef cattle are killed, the numbers are small, since there are few large feedlots in the data. Sheep are infrequently destroyed. Finally, the low-destruction outcome for the direct-contact slaughter scenario is the same as the indirect-slaughter scenario, 4,559 market hogs.

For the direct-contact slaughter control strategy, the shortest outbreak lasts 16 days, with the longest running for 186 days. The average length is 56.48 days. Results for the direct- and indirect-slaughter strategy are similar, with the shortest outbreak being 16 days, the mean 54.99 days, and the longest 188 days. The ring-destruction scenario results differ from the other results because the outbreak durations are much shorter. The shortest outbreak under ring destruction lasts 15 days. The mean length is 36.8 days, nearly 20 days shorter than with the other control options. The longest outbreak under ring slaughter is only 64 days, compared with more than 180 days for the other control strategies. Consequently, U.S. red meat and animal exports are halted for two quarters in all outcomes except the high outcomes for direct-slaughter and for direct- and indirect-slaughter strategies. Those two outcomes show FMD cases appearing in quarter 3. However, since there are only 6 to 8 days in the third quarter where cases appear, export reductions in the fourth quarter are prorated to 89 and 90 percent of the base level.

Economic Impacts of an FMD Outbreak

The shocks described above from the NAADSM component of the model are inserted into the quarterly model of U.S. agriculture as percent changes, and the model is solved for 16 quarters to determine the economic impacts of the FMD outbreak. The quarterly agricultural sector solves for the percent changes in the endogenous variables. The percent changes are applied to a baseline formed by the observed data for the first quarter of 2001 through the fourth quarter of 2004. Thus, actual market price and quantity movements during that 16-quarter period are reflected in the baseline.

Several key assumptions influence economic results. One assumption in this analysis is that all U.S. exports of beef, pork, lamb meat, cattle, swine, and lambs and sheep are halted during the full quarters of the outbreak and for one quarter after the last case appears. Interrupting exports for one quarter beyond the end of the outbreak is consistent with Office International des Epizooties (OIE) guidelines and practices during FMD outbreaks. When that additional quarter ends with no FMD reported, we assume that U.S. exports of the embargoed products fully recover to base levels. Thus, the duration of the outbreak becomes a critical element in determining the economic effects from trade disruptions.

Another critical set of assumptions involves livestock grower expectations regarding prices and future returns. In the model, animal production decisions are based on expected future returns relative to current prices for animals. For example, if a cattle rancher expects that prices for cattle nine quarters in the future will be unaffected by the current disease outbreak, breeding animal inventories and calf production will change little. In the model, expectations are set by the modeler, and price expectations in the scenarios are assumed constant.

Finally, U.S. consumers are assumed to be aware that transmission of FMD to humans is so rare that it is virtually nonexistent. Thus, the scenarios assume there is no disease-induced reduction in demand for beef, pork, and lamb meat.

The results can be grouped into two sets to facilitate presentation:

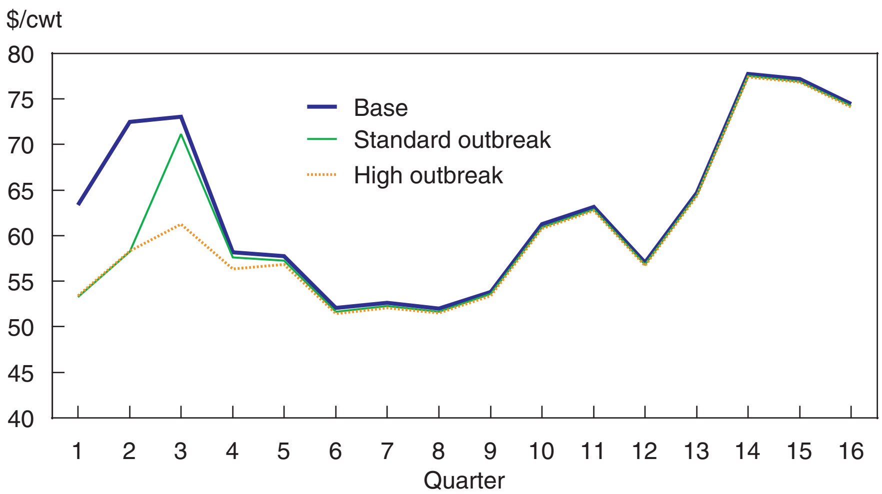
- Standard-outbreak scenario: So called because of the nine outcomes, seven are very similar: There is little difference among the three solutions for 1 km ring destruction, or between low and mean outcomes under the direct-contact slaughter and the direct and- indirect-contact slaughter control strategies and the ring outcomes. Thus, all seven outcomes can be summarized as the results of the mean direct- and indirect-destruction strategies.
- High-outbreak scenario, consisting of two outcomes that differ from the standard-outbreak scenario, but that are themselves similar: the high results for direct-contact and indirect-contact destruction.

The primary result that separates the nine outcomes into the two groups is the duration of the outbreak. The seven outcomes that form the standard-outbreak scenario all have durations shorter than one quarter. The two differing high-outbreak scenario outcomes have outbreaks lasting 186 to 188 days, or slightly into quarter 3. Export disruptions end one full quarter after slaughter of the last animal associated with the outbreak. Thus, the export disruption for the standard outbreak ends two quarters after the outbreak begins, whereas in the more extreme case, U.S. exports show impacts into quarter 4. Because relatively small numbers of animals are destroyed in these scenarios, trade impacts overwhelm the supply shocks that occur from the destruction of animals.

Pork and Hogs

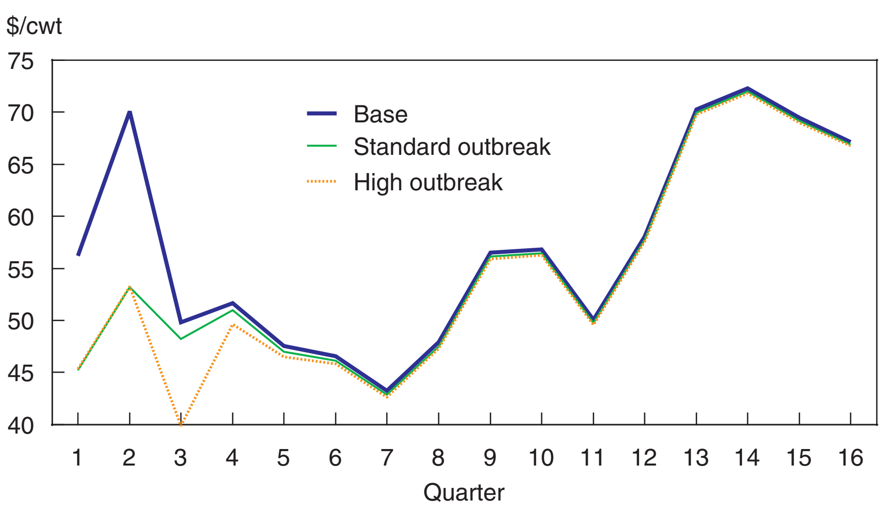
Because most of the animals destroyed are hogs, and exports of pork and hogs are restricted, those sectors are where much of the impact of an FMD outbreak is felt (figs. 2 and 3). An FMD outbreak sharply lowers the prices of pork and hogs under both the standard-outbreak and the high-outbreak

Figure 2
Price of pork (carcass cutout value)



Source: Model simulation results.

Figure 3
Price of hogs



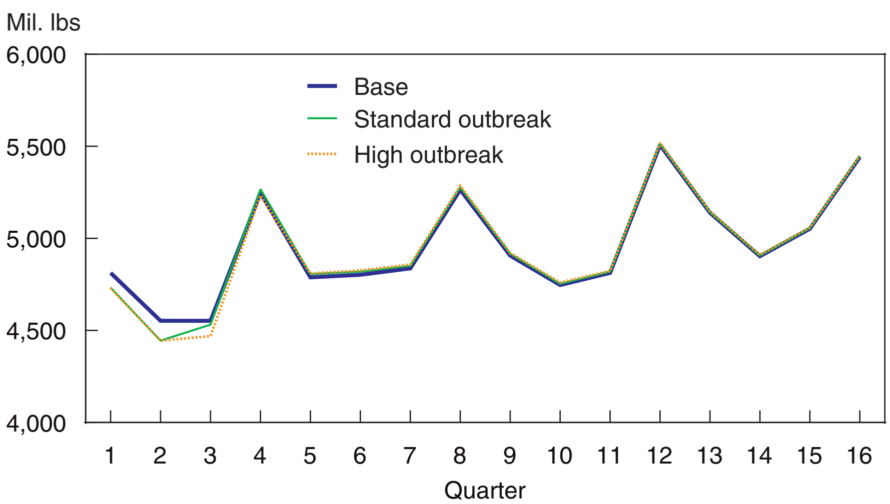
Source: Model simulation results.

scenarios (figs. 2 and 3). Again, this is because trade impacts are larger than depopulation shocks. During the first quarter after the outbreak begins, pork prices (cutout value) fall from $63.33 to $53.26 per cwt, while prices of live hogs in the first quarter fall from $56.52 to $45.20 per cwt. Pork and hog prices decline because of increased domestic supplies that result from import bans imposed by trading partners. Second-quarter pork and hog prices remain well below base-scenario prices.

One difference in the patterns of hog and pork price changes is that actual hog prices used in the baseline rise rapidly from the first-quarter price level to $70 per cwt. In the third quarter, differences in the solutions begin to appear for two reasons: (1) the observed base pork and hog prices behave differently—whereas the observed base pork prices are stable, the base hog price falls by $20 per cwt due to the expansion of the hog industry in 2001, and (2) in the high-outbreak scenario, the outbreak continues into the third quarter, meaning that the export restrictions continue. As a result, prices in the standard-outbreak scenario rise toward the baseline because the outbreak has ended and export restrictions are lifted. Prices in the high-outbreak scenario remain depressed because the export restrictions remain. Pork prices rise slightly in the third quarter, relative to the stable base price, because of the compounding effects of hogs lost to disease on the cost of supplies in quarters 1 through 3. The hog price falls in the third quarter because the observed base price falls as hog numbers rise during that period. Note that the base hog price falls $20 per cwt, while the high-outbreak hog price falls $6 per cwt, so the gap between the standard- and high-scenario prices narrows, just as it did for pork prices.

For pork output, the first-quarter difference with the baseline is a decline of 1.6 percent, where output falls from 4,812 to 4,733 million pounds (fig. 4). While there is a small decline in the number of finished hogs due to the disease, the most readily available means of adjusting to the domestic decline is through importing slaughter hogs from Canada. With lower pork prices and return to capital, the incentive to import and kill hogs is reduced. Total

Figure 4
Pork output



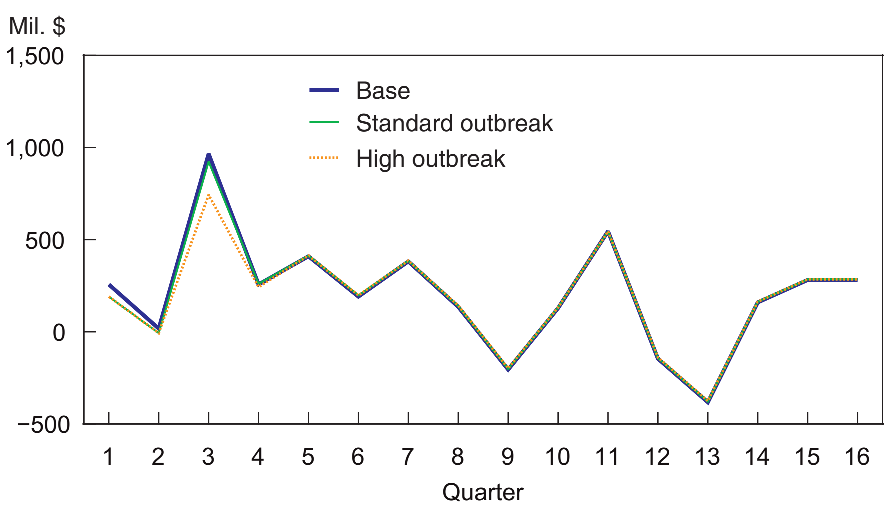
Source: Model simulation results.

first-quarter hog slaughter falls from 23,692,000 to 23,588,000 head. The largest drop in output occurs in the second quarter, because the effects of animal destruction are compounded and price declines relative to the baseline are the largest. Pork output declines 2.3 percent, from 4,550 to 4,444 million pounds. In the standard-outbreak scenario, third-quarter pork output approaches the baseline value to within a difference of -0.5 percent. The high-outbreak scenario continues to show a difference in output, -1.8 percent. The process of returning to the baseline is effectively completed by quarter 6 for both scenarios.

For pork consumption, changes in these scenarios are driven by changes in prices. With lower prices, pork consumption rises in quarters 1 and 2 for the standard-outbreak scenario. In the high-outbreak scenario, the domestic supply effects from the loss of exports into quarter 4 cause prices in quarter 3 to be lower, so pork consumption is higher.

As a result of an FMD outbreak, lower pork prices and output translate into reduced return to capital and management in the pork processing and packing sector (fig. 5). Large reductions in returns to processing hogs occur in quarters 1 and 2. The base returns in quarter 1 are $256 million. With the FMD outbreak, returns fall to $191 million. For quarter 2, baseline returns of $17 million are reduced to losses of $9 million. As with the other variables, the scenarios begin to diverge in quarter 3. The returns in the standard-outbreak scenario are $923 million, compared with the baseline value of $965 million, whereas the high-outbreak returns are only $742 million. By quarter 4, the gap in returns under the standard-outbreak scenario has been closed, but the difference in the high-outbreak scenario remains $12 million. By quarter 5, both scenarios are converging on the baseline.

Figure 5
Returns to capital and management, pork processors to retailers

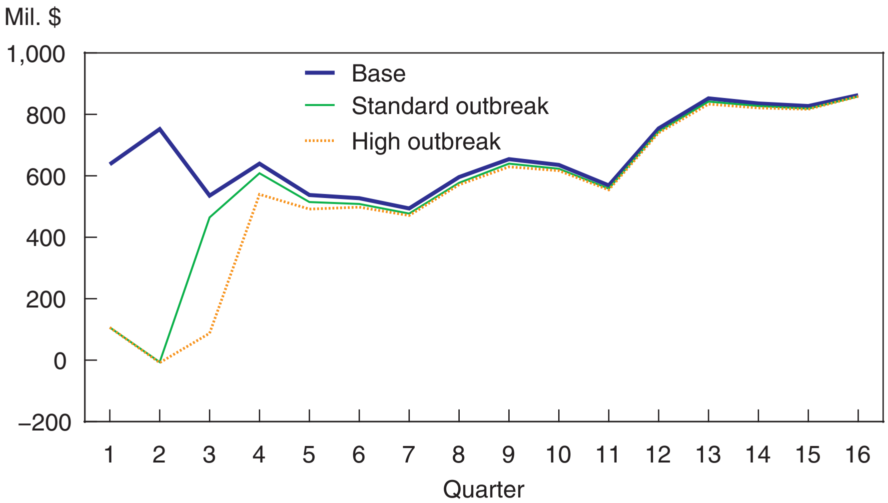


Source: Model simulation results.

Returns to capital and management for hog growers reflect the patterns seen in the prices (fig. 6). Both scenarios show large reductions in the first quarter, with returns falling from a base value of $638 to $107 million. The second-quarter decline is larger, with returns of -$12 million vs. $751 million. Third-quarter returns to capital and management recover to within $70 million below the baseline under the standard-outbreak scenario, but returns in the high-outbreak scenario are $448 million below the baseline. By the sixth and seventh quarters following the FMD outbreak, returns to hog growers have recovered almost to the baseline levels.

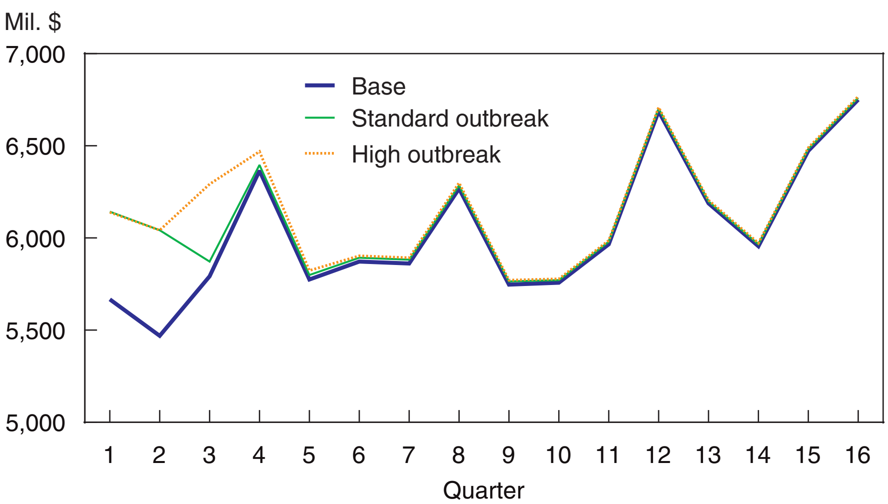
The economic welfare of consumers is measured by the difference between what consumers are willing to pay and what they must pay for each unit consumed. This difference is called consumer surplus. Since the FMD outbreak causes exports of pork to be restricted, the price of pork falls and the lower price causes a gain in consumer surplus (fig. 7). The gap between

Figure 6
Returns to capital and management, hog producers



Source: Model simulation results.

Figure 7
Consumer surplus for pork



Source: Model simulation results.

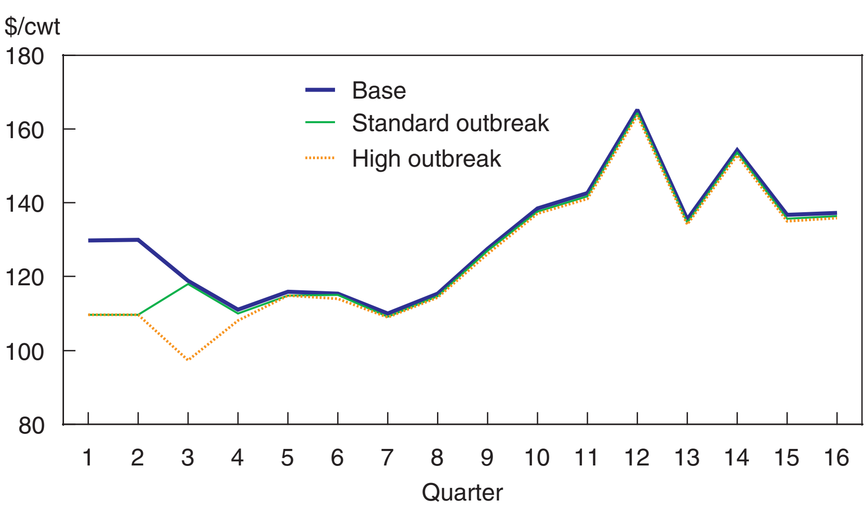
the willingness to pay for each unit consumed and what they must pay expands. In the first quarter, gains to consumers are around $478 million. The second-quarter gain is $573 million, because the gap between the baseline price and the model solution price is larger. In the third quarter, the restoration of exports in the standard-outbreak scenario returns consumer surplus to within $80 million. The high-outbreak scenario has a consumer gain of $499 million because exports remained embargoed. During the fourth and fifth quarters, benefits to consumers from lower prices continue to shrink and are small.

Beef and Beef Cattle

The beef and beef cattle sectors are also strongly affected by the FMD outbreaks (figs. 8 and 9). The initial patterns appear similar to those for pork and swine. The FMD outbreak causes large initial declines in the prices for beef and for cattle, again because trade restrictions dump extra supplies on the domestic market (i.e., a domestic supply shock). The first-quarter cutout value for beef drops from $129.69 to $109.57 per cwt, a fall of 16 percent. The live-steer price falls from $79.17 to $64.69 per cwt, a drop of 18 percent. The end of U.S. export restrictions after the second quarter in the standard-outbreak scenario causes a price recovery for both beef and cattle, starting during the third quarter. The high-outbreak scenario, where the export restrictions remain into the third quarter and beyond, shows a further weakening of prices. Both scenarios show recovery of prices beginning after the end of export restrictions.

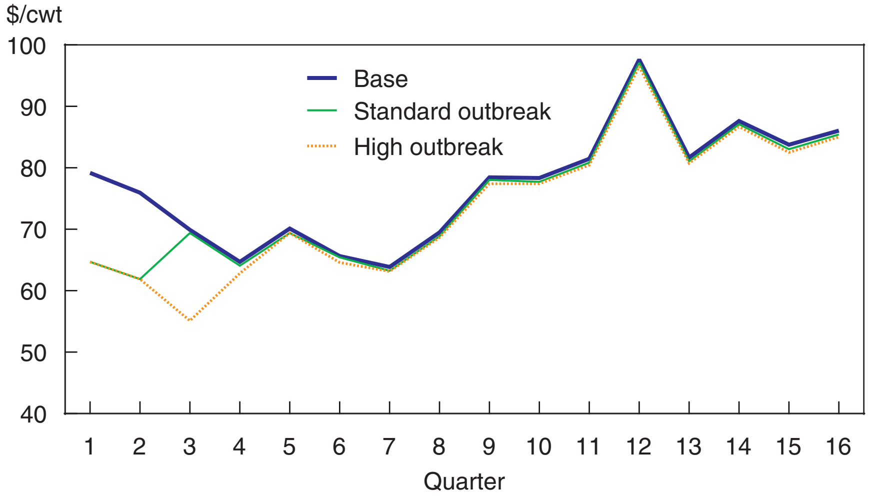
Beef output shows little difference in the effects of the two outbreak scenarios over the 16-quarter period (fig. 10). In the first few quarters, beef production is slightly higher, despite slightly lower slaughter. For example, in quarter 1, beef production rises from 6,272 to 6,379 million pounds, while the number of cattle slaughtered falls from 7,581,000 to 7,579,000 head.

Figure 8
Price of beef (carcass cutout value)



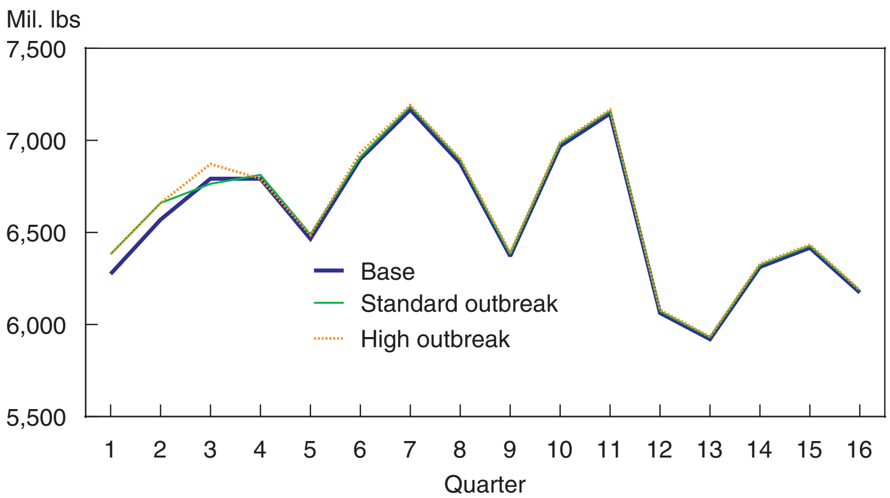
Source: Model simulation results.

Figure 9
Price of cattle



Source: Model simulation results.

Figure 10
Beef output



Source: Model simulation results.

Changes in meat yields per animal depend on the difference in the change in the cattle price relative to the rent on capital in the beef industry and the elasticity of substitution. Slaughter weights are 1.6 percent larger, since the price decline for cattle is greater than that for beef. Weights rise from 753.3 pounds per animal to 765.2 pounds. Packers substitute cattle for capital as the price of cattle falls more than the rent on capital by running the plants slightly more slowly, with closer trim. Given the time lags in raising an animal for slaughter, adjustments are muted.

Imports of slaughter cattle are reduced under both outbreak scenarios, but imports account for a small share of total cattle slaughter. Once U.S. export restrictions are removed, changes occur in the relationship between slaughter numbers and slaughter weights. Slaughter weights drop slightly below baseline weights; fourth-quarter weights are 783.8 vs. 784.5 pounds in the base. The number of animals slaughtered rises, because low cattle prices in quarters 1 through 4 relative to static price expectations cause ranchers to hold more cattle in inventory, and larger cow inventories result in larger calf crops. Larger inventory and calf crops mean more animals for slaughter after quarter 5. Quarter-5 slaughter is 7,615,000 head, compared with 7,575,000 head in the baseline. The resumption of U.S. exports boosts U.S. prices, and U.S. imports of slaughter cattle increase. These adjustments, although small, do result in slightly more beef output in quarters 4 through 16.

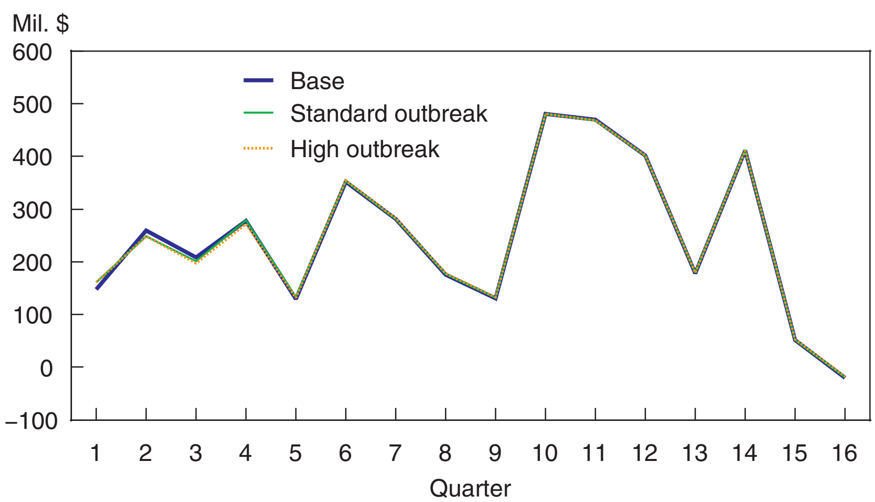
Because demand for beef is unchanged in these scenarios, the supply shifts result in beef consumption that is driven by price changes. Higher slaughter volume and higher slaughter weights lead to lower beef prices (below baseline levels), and beef consumption rises. The increase in first-quarter consumption is 7.1 percent. As beef prices rise toward baseline levels, consumption declines toward baseline levels.

Lower prices for beef and cattle following an FMD outbreak affect returns to capital and management (fig. 11). The first-quarter return is $13 million higher, or a 9.1-percent increase. The FMD outbreak lowers returns to capital and management in the second quarter from $259 to $249 million, a decline of 3.9 percent. With the end of U.S. export restrictions, returns begin to climb back to the baseline. For the standard-outbreak scenario, that climb occurs in quarter 3, whereas for the high-outbreak scenario, the recovery to the baseline starts in quarter 4. By quarter 10, little difference remains.

Figure 12 converts FMD-response-motivated price declines (fig. 9) into returns to capital and management for beef cattle producers. Positive baseline returns of $1,035 million become outbreak-associated returns of $216 million (fig. 12). In the high-outbreak scenario, U.S. export restrictions result in low returns that continue into quarter 3. As export restrictions are relaxed, net returns to capital and management start to recover.

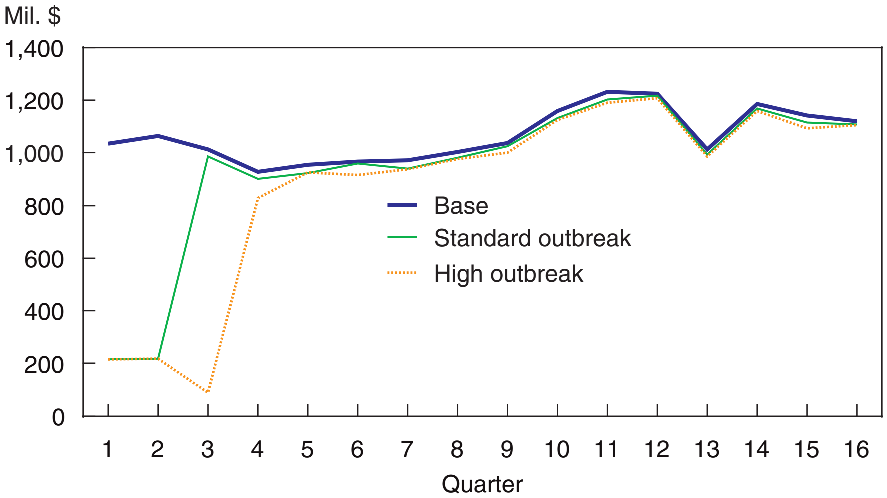
Figure 11

Net returns to capital and management, beef processors to retailers



Source: Model simulation results.

Figure 12
Net returns to capital and management, beef cattle producers



Source: Model simulation results.

With beef prices falling due to the U.S. export restrictions, consumer welfare increases (fig. 13). Consumer surplus in the first quarter rises from $9,646 to $11,034 million. In the standard-outbreak scenario, consumer surplus in quarters 2 and 3 is above baseline values by $1,538 million and $66 million, respectively. The longer export prohibition in the high-outbreak scenario generates additional gains in quarters 3, 4, and 5.

Dairy and Milk

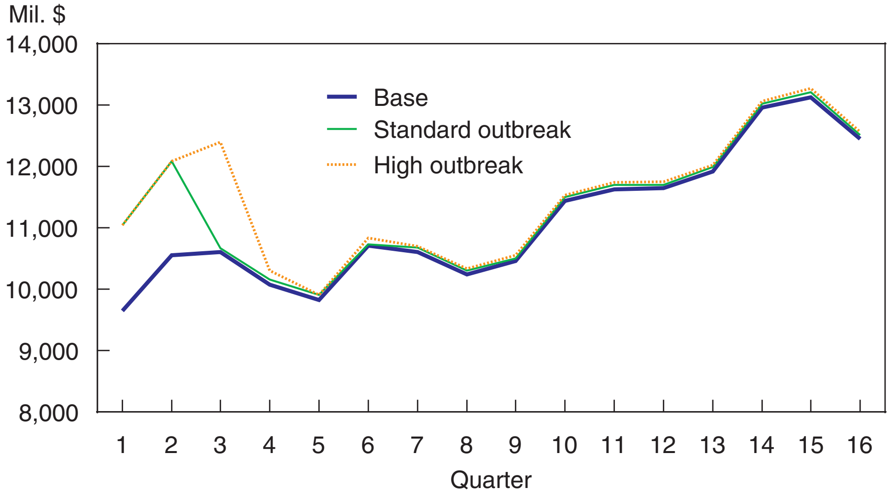
The milk and dairy sector is modeled on a milk basis. The FMD outbreak has no significant impact on the price of milk because few dairy animals are destroyed relative to the size of the national herd, and no exports of dairy products are banned (fig. 14). For the other commodities discussed, it is primarily the export shock that drives the results, and that shock is missing here.

Since milk prices are not affected much by the FMD outbreak and few dairy cattle are destroyed in the scenarios, the impacts on other variables are small. Milk production and consumption correspond to the baseline levels. Net returns to capital and management in the dairy sector are largely unaffected.

Poultry and Eggs

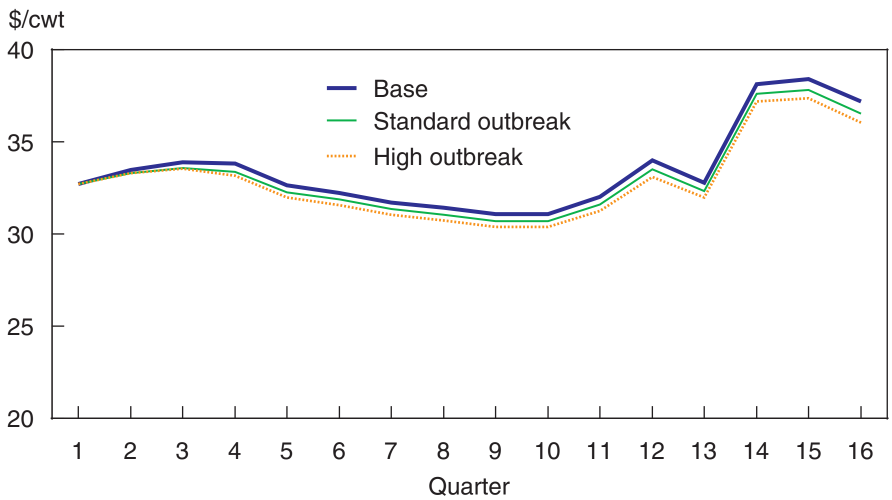
Poultry meat and eggs are not directly affected by an FMD outbreak. The impacts operate through cross-price impacts in demand and through the impacts on feed prices. For poultry meat prices, these impacts are not large (fig. 15). Prices weaken somewhat in sympathy with the prices of beef and pork, but since the cross-price effects are small, the price decline is small. With few animals killed during the outbreak, the effects on feed prices are not large. Poultry meat production is slightly lower. First-quarter poultry meat output falls from 8,896 million to 8,762 million pounds, or 1.5 percent. First-quarter net returns fall from $538 million to $506 million, or 5.9 percent (fig. 16). Returns recover to the baseline by quarter 4.

Figure 13
Consumer surplus for beef



Source: Model simulation results.

Figure 14
Retail price for milk



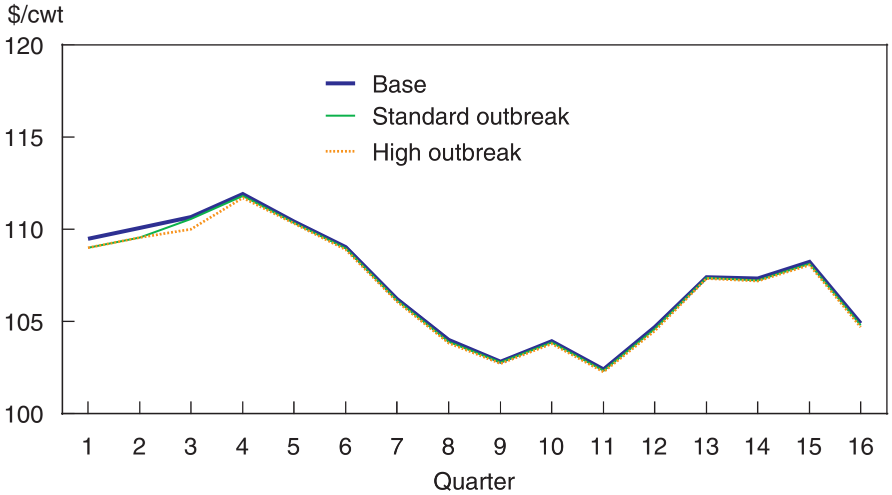
Source: Model simulation results.

If poultry movements were restricted during an FMD outbreak, there would be additional impacts. However, since well under 10 percent of poultry production is located in the Midwest, the impacts would likely be small in the scenarios presented here.

Lamb and Sheep Stocks and Meat

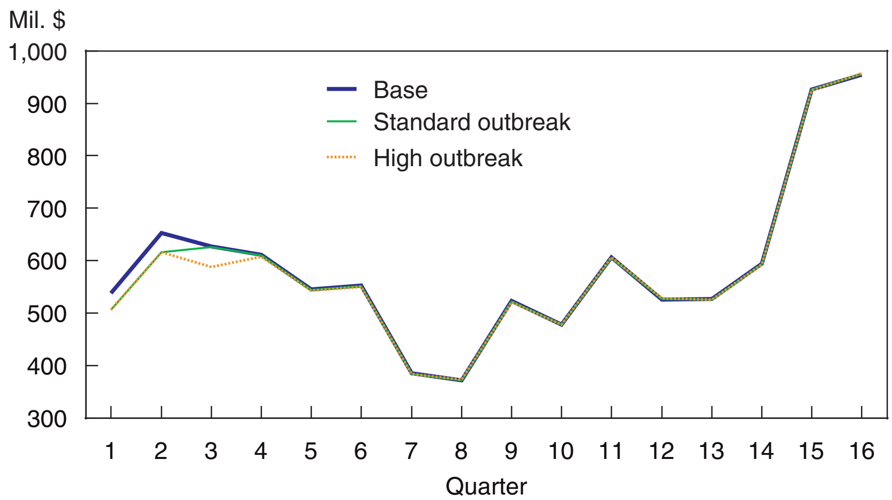
The number of lambs and sheep destroyed in the outbreak is negligible, and the United States exports little meat or few live animals, except for cull ewes to Mexico. In fact, the United States imports a large share of its lamb meat supplies, reducing any impact of animal destruction on meat supply. Thus, the impact on these sectors is not large compared with the other red meat sectors. The first-quarter price of lamb meat falls by 2.4 percent as consumption declines when consumers switch to lower-priced beef. Since imports

Figure 15
Retail price of poultry meat



Source: Model simulation results.

Figure 16
Net returns to capital and management, poultry meat



Source: Model simulation results.

are more elastic, they show a greater adjustment. U.S. imports decline by 9.6 million pounds, and domestic lamb meat production rises by 5.4 million pounds. The percent increase in production exceeds the percent decline in price, so the value of production increases slightly.

In the lamb and sheep markets, U.S. live animal exports are reduced by 74,700 animals in quarter 1. These animals are added to slaughter, which boosts meat output. The additional animals sold on the U.S. domestic market result in animal price declines from the baseline value of $79.55 to $73.33 per cwt. Total revenue is slightly greater, and so are net returns to capital and management.

Crops

With so few animals destroyed and the short duration of the outbreak, there is little effect on feeding. Corn, wheat, and soybean prices decline very slightly. Even if prices had changed greatly, government payments would adjust to preserve net returns.

Changes in Aggregate Net Returns to Capital and Management

The changes in net returns to capital and management, summed over 16 quarters, give the most comprehensive overview of the cost to agriculture and agribusiness of the assumed FMD outbreaks (table 15). Since the impacts dampen over time, most of the effects occur in the first four quarters.

The beef packing/processing and beef cattle sectors show the largest losses from the assumed outbreaks, even though the number of cattle destroyed is small. The combined losses range from $1,951 million to $3,075 million. Pork and swine sectors experience losses in returns to capital and management of between $1,652 million and $2,358 million. Returns in the dairy sector improve, because few dairy cattle are lost to FMD and dairy exports do not decline, while feed costs—especially the cost of forage—are lower. Other sectors experience either small losses in returns to capital and management or small gains, as in the case of lamb and sheep meat and milk. Total losses to capital and management over 16 quarters amount to between $2,773 million and $4,062 million.

Conclusions

This report presents a modeling framework designed to estimate the economic impacts of livestock disease outbreaks. The combined framework is designed to examine the impacts of highly contagious livestock diseases and alternative control and surveillance options. The framework has three key features: (1) the initial disease-spread component can be based on an epidemiological model that incorporates disease-spread parameters; (2) supply shocks, along with demand and trade shocks, can be introduced into a model of the U.S. agricultural sector; and (3) time is disaggregated into a quarterly model of the U.S. agricultural sector in which economic shock dynamics can be observed over 20 quarters. Only 16 quarters were examined in this simulation study because the short duration of impacts resulted in no differences from the baseline in the latter quarters.

A hypothetical FMD outbreak is used to illustrate the utility of the modeling framework. In our example, the initial outbreaks arise from using garbage as feed in four small farrow-to-finish operations in the Midwest. Three alternative control strategies and three levels of disease-outbreak intensity are examined. The strategies considered are destruction of direct-contact herds, destruction of direct-contact and indirect-contact herds, and slaughter of all animals within a 1-km ring. The disease-spread model is solved 50 times for each scenario to give mean, low, and high outcomes. Exports of beef, pork, lamb meat, cattle, hogs, lambs, and sheep are assumed to be halted during the outbreaks, with restrictions continuing for one quarter beyond the slaughter of the last confirmed case associated with the outbreak.

For our hypothetical FMD scenario, the epidemiological model estimates destruction of relatively small numbers of susceptible animals, a maximum of 77,582 out of a susceptible population of 9.8 million animals in the database used. Despite the small numbers of animals slaughtered, the economic model results show large losses to capital and management for beef, beef cattle, hogs, and pork. These losses are a direct result of the increased domestic supplies that occur with the loss of trade under our trade assumptions, which lead to lower prices. However, dairy sector returns to capital and management increase because few dairy cattle are destroyed, exports are not restricted, and feed costs are lower. Other sectors experience small losses or, in some cases, small gains.

Because loss of U.S. exports is linked to length of an outbreak, control strategies that reduce the duration of the outbreak predominate. The most extreme, ring destruction, always reduces the length of an outbreak to less than one quarter. The mean- and low-outbreak cases for direct-contact slaughter and direct-and-indirect-contact slaughter also reduce the outbreak to one quarter. But these control strategies exhibit some iterations in which FMD outbreaks last beyond two quarters, triggering export losses into the fourth quarter after the hypothetical outbreak. Under direct-contact and a combination of direct- and indirect-contact slaughter, the total U.S. loss of net returns to capital and management in agriculture and agribusiness ranges from $2,773 million to $4,062 million in our scenario, while U.S. consumers benefit from lower prices during the quarters in which U.S. exports are assumed to be embargoed.

A number of variations could alter the results presented here. One factor that may affect the outcome of control strategies is the type of outbreak. Animal losses and length of outbreak are sensitive to assumptions about the type of outbreak. While in our examples the outbreaks occur in small hog operations in the U.S. Midwest, control strategies that predominate could be different for outbreaks that (1) occur in larger operations with more off-farm movement, (2) differ spatially, or (3) originate with a different species. In particular, the effectiveness of ring destruction in lowering the duration might not hold, and costs could be larger than reported in this analysis. Other control strategies could also yield results that differ from those observed in this study, including vaccination strategies, regionalization, quarantine-zone policy alternatives, and marketing potential for uninfected livestock slaughter. For example, if a quarantine policy restricted poultry movements within quarantine zones during an FMD outbreak, or if meat from uninfected livestock could be marketed through normal channels, results could be different.

A poultry version of the framework has been developed to examine the impacts of trade regionalization in the event of a hypothetical outbreak of Highly Pathogenic Avian Influenza (Paarlberg, Seitzinger, and Lee, 2007). Another way the model presented here could be used is to examine policy-switching strategies. For example, the model could give an indication of the impacts of switching to a vaccination policy after a period of time when disposal resources become overwhelmed, as they did during the 2001 FMD outbreak in the Netherlands (de Klerk, 2002; Pluimers et al., 2002).

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Appendix A—A Conceptual Model of the Agricultural Sector

Efficient modeling of the impacts of foreign animal diseases in the United States requires integrating a disease-spread model with an economic model. The general approach follows that of Jones (1981) and Sanyal and Jones (1982). The model and application are based on several key assumptions: Economic agents are assumed to be price-taking maximizers of well-defined objective functions. Consumers are assumed to select a consumption vector that maximizes a well-defined, homothetic utility function, given their income and prices. The utility maximization problem for a consumer gives a set of per capita demand functions. Producers (firms or farms) are assumed to select an input-output vector that maximizes profits, subject to a well-defined, constant-returns-to-scale production function. There are four types of inputs, or factors of production: (1) mobile among production activities (e.g., labor, fuel) and in perfectly elastic supply, so the price is treated as given, (2) sector-specific intermediate goods (e.g., hogs for pork), (3) sector-specific primary factors (e.g., physical and human capital), and (4) land, which is mobile across crop production. Land used in livestock production is treated as land used for forages and pasture. Thus, the model has the structure of a Ricardo-Viner or Specific-Factors model, where perfect competition prevails.

Final Consumer Demand

Based on the above assumptions, the demands for final goods are straightforward. Let $\mathbf{DP}_t$ be a column vector of per capita consumption for final goods in quarter t. Final goods in the model are beef, pork, poultry meat, lamb and sheep meat, eggs, milk, wheat, coarse grains, rice, and soybean oil. $\mathbf{DP}_t$ is a vector of per capita demand functions, $DP_i(\ldots)$, each of which depends on a vector of retail prices for the final goods, $\mathbf{PR}_t$, and a scalar, per capita income, y_t:

(1) $\mathbf{DP}_t = \mathbf{DP}_t(\mathbf{PR}_t, y_t)$.

Total consumption of final goods in the U.S. economy in quarter t depends on per capita consumption multiplied by the scalar population at time t, pop_t, and a column vector α, $0 \leq \alpha_j \leq 1$, of parameters that indicate the share of the population unafraid of a health risk associated with each final good. Thus, α is a potential disease outbreak shock instrument in cases where consumers fear a health risk: If $\alpha_j = 1$, consumers do not fear a health risk. The vector of total consumption of final goods, $\mathbf{DF}_t$, is:

(2) $\mathbf{DF}_t = pop_t * \alpha_t * \mathbf{DP}_t$.

Supplies of Final Goods

Meat, Milk, and Egg Production

Meat, milk, and eggs are produced by separate industries (sectors). Firms in the production of individual meats do not earn super-normal profits, so a zero-profit condition holds for each meat, as well as for milk and eggs. Production is assumed to occur at time t. Three types of production factors are used. Prices for factors in perfectly elastic supply are exogenous and denoted with a column vector $\mathbf{W}_t$. Prices for the animal intermediate inputs are denoted by the vector $\mathbf{PA}_t$ while prices for the sector-specific primary factors are denoted as $\mathbf{R}_t$. Unit cost under the constant-returns-to-scale technology is a function of only factor prices, $\mathbf{CM}(\mathbf{W}_t, \mathbf{PA}_t, \mathbf{R}_t)$. Let $\mathbf{PM}_t$ be the wholesale prices of meats, milk, and eggs at time t. With perfect competition and constant returns to scale, the zero-profit conditions are:

(3) $\mathbf{CM}(\mathbf{W}_t, \mathbf{PA}_t, \mathbf{R}_t) = \mathbf{PM}_t$.

Determining production of meats, milk, and eggs requires inclusion of factor-market-clearing conditions. Define **AM** as the matrix of per unit demands for factors of production in the meat, milk, and egg industries, with $\mathbf{QM}_t$ the column vector of outputs of meats, milk, and eggs at time t. Let the column vector **Z** consist of a partition $[\mathbf{K}_t, \mathbf{DA}_t]^T$ where $\mathbf{K}_t$ indicates primary, sector-specific factors in fixed supply and $\mathbf{DA}_t$ denotes the derived demands for animals at time t. Given the above assumptions, **AM** depends only on factor prices, so the factor-market-clearing conditions are:

(4) $\mathbf{AM}(\mathbf{W}_t, \mathbf{PA}_t, \mathbf{R}_t)*\mathbf{QM}_t = \mathbf{Z}$.

The vertical linkages to animal agriculture are established through **Z** in equation (4), along with $\mathbf{K}_t$, through the derived demand for animals for slaughter ($\mathbf{DA}_t$). In general, these linkages proceed from slaughter, net of trade, back through livestock inventories, into the derived demands for feedstuffs. In this way, not only are linkages established for final products and the livestock sectors, but linkages are also established to crops and their factors of production. Because each type of animal has unique features, each type is presented individually.

Beef Cattle

The beef cattle market clears via a market price, Pc_t, determined by a market-clearing identity. That identity requires that beef animals slaughtered at time t, Dc_t, equal finished cattle from calves born five quarters previously, Sc_{ft}, and dairy cows culled, Sdc_t, plus imports of cattle for slaughter, Mc_t, less cattle exported, Xc_t:

(5) $Dc_t = Sc_{f,t} + Sdc_t + Mc_t - Xc_t$.

Beef cattle born five quarters previously are finished at time t and have moved through a production process. Animals born in quarters t-3 and t-4 are in the grower and backgrounding stages at time t, denoted $Sc_{g,t}$ and $Sc_{b,t}$. These cattle will be finishing at time t+1 and t+2. Animals in their preweening stage at time t, $Sc_{w,t}$ are linked to quarter t-2 births and will be finished at time t+3. The post-birth stage, $Sc_{p,t}$, is linked to calves born at t-1 that will be finished at time t+4. A disease outbreak means a policy of stamping out, or possibly natural deaths, so a mortality rate parameter, $\lambda_{c,j}$, $0 \leq \lambda_{c,j} \leq 1$, j = f, g, b, w, p, is inserted to reflect a reduction in cattle numbers. Thus, the flow of market cattle through the production stages is captured by the following equations:

(6) $Sc_{f,t} = \lambda_{c,f} Sc_{g,t-1}$

(7) $Sc_{g,t} = \lambda_{c,g}Sc_{b,t-1}$

(8) $Sc_{b,t} = \lambda_{c,b}Sc_{w,t-1}$

(9) $Sc_{w,t} = \lambda_{c,w}Sc_{p,t-1}$

Calves born in the quarter reflect the beef cow inventory, Ic_t, and since disease outbreaks can affect the rate of abortions and calf mortality, the term $\lambda_{c,p}$ is included to measure calves lost (equation 10):

(10) $Sc_{p,t} = Sc_p(Ic_t, \lambda_{c,p})$.

Cattle trade is linked to U.S. market prices for cattle, to trade policy, and to any disease outbreaks. Trade policy intervention is modeled as a specific trade intervention, tc, with trade determined by the U.S. domestic price less the specific trade intervention. Because an animal disease outbreak can disrupt trade, parameters γm_c and γx_c, ranging from 0 to 1, are used to indicate the severity of trade restrictions. Thus, trade behavior is described as:

(11) $Mc_t = Mc(Pc_t - t_c)*\gamma m_c$;

(12) $Xc_t = Xc(Pc_t - t_c)*\gamma x_c$.

Each stage has unique derived demands for feed. There are four types of feed available in the model, wheat (w), coarse grains (g), soybean meal (sm), and forages and pasture (fo). Use of feed ingredient i (= w, g, sm, fo) by fed cattle at stage j at time t is given by $as_{i,j,t}$, which is a function of feed prices. Total demand, $DSc_{i,j,t}$, is the per animal use multiplied by the number of cattle consuming feed in each stage:

(13) $DSc_{i,j,t} = as_{i,j,t}(Pw_t, Pg_t, Pfo_t, Psm_t)*Sc_{j,t}$
for i = w, g, fo, sm and j= f, g, b, w, p.

The decision to hold an animal for breeding at time t reflects two effects. One is the expected relative profitability of producing calves for future sale plus the utility cow value at time t+9 compared with selling the cow for slaughter at time t (Rosen, 1989). Thus, beef cow inventory at t, (equation 14) is partly explained by the expected return to retaining a heifer for breeding at time t, Rc^e_t, where the "e" indicates expectations relative to the current cattle price, Pc_t. The expected return is the utility value of the cow plus the values of two future calves. Another factor is the previous quarter's inventory, since cow inventories cannot be immediately rebuilt. The coefficient on the lagged inventory controls the speed of adjustment. Also, any disease-induced losses, γc, must be recognized. Thus:

(14) $Ic_t = Ic(Rc^e_t/Pc_t, Ic_{t-1})*\gamma c$.

Cows have unique feed requirements. Define the per cow feed ingredient requirement at time t as $ac_{i,t}$. These per cow demands depend on the feed ingredient prices and season of the year. Demand for feed ingredient i by cows at time t, $DC_{i,t}$, are the per cow ingredient demands multiplied by the inventory:

(15) $Dc_{i,t} = ac_{i,t}(Pw_t, Pg_t, Pfo_t, Psm_t)*Ic_t$

where i = w, g, fo, sm.

Replacement heifers at time t, Hct, affect cow inventory eight quarters in the future. The decision to raise a replacement heifer is based on the expected return, Rc^e, at time t+16 from a retained heifer, balanced against the expected market value of a heifer fed for five quarters. As in other cases, a disease outbreak could result in a loss of replacement heifers, λh, so total replacement heifer inventory entering at t is:

(16) $Hc_t = Hc(Rc^e_{t+16} / Pc^e_{t+5}, \lambda h)$.

Each replacement heifer will have quarterly feed demands based on the season. Let $ah_{i,t}$ be the per heifer feed use of feed i. The feed use of each ingredient at time t by heifers, $DH_{i,t}$, will depend on the prevailing prices and the number of heifers:

(17) $Dh_{i,t} = ah_{i,t}(Pw_t, Pg_t, Pfo_t, Psm_t)*Hc_t$

where i = w, g, fo, sm.

The number of bulls, Bc_t, is exogenous, as these inventories vary little. Each bull consumes feed based on the season (quarter):

(18) $Db_{i,t} = ab_{i,t}(Pw_t, Pg_t Pfo_t, Psm_t)*Bc_t$.

Swine Production

The swine component is similar to that for beef, but requires fewer stages and quarters. Slaughter hogs are assumed to be produced two quarters after farrowing. The market price for hogs, Phg_t, is determined where slaughter, Dhgt, equals market hogs, Shgt, from the pig crop produced two quarters earlier, PIG_t-2, plus imports of slaughter hogs, $Mhgs_t$, less exports of hogs for slaughter, $Xhgs_t$:

(19) $Dhg_t = Shg_t + Mhgs_t - Xhgs_t$.

Trade of slaughter hogs depends on the market price of hogs, a specific trade intervention, t_{hg}, and parameters ranging from 0 to 1 that indicate the restrictiveness of trade following a disease outbreak, γm_{hg} and γx_{hg}:

(20) $Mhgs_t = Mhgs(Phg_t - t_{hg})*\gamma m_{hg}$;

(21) $Xhgs_t = Xhgs(Phg_t - t_{hg})*\gamma x_{hg}$.

Hogs for market at time t are the pigs at time t-2 plus feeder pigs coming in from Canada at time t-1, $Mhgfd_{t-1}$, less any exports of feeder pigs, $Xhgfd_{t-1}$. Because a disease outbreak could affect the number of animals available for slaughter, a scalar, λs, $0 \leq \lambda s \leq 1$, is introduced:

(22) $Shg_t = Mhgfd_{t-1} + \lambda s*PIG_{t-2} - Xhgfd_{t-1}$.

Trade of feeders follows the same specification as for slaughter hogs:

(23) $Mhgfd_t = Mhgfd(Phg_t - t_{hg})*\gamma m_{hg}$,

(24) $Xhgfd_t = Xhgfd(Phg_t - t_{hg})*\gamma x_{hg}$.

Gestation for hogs is about 4 months, so pigs born in period t depend on the numbers of sows in period t-1, Isw_{t-1}, a variable, αs, to account for increased abortions, and the relative price of future hogs compared with the market value of a sow last quarter (Phg^e_{t+2}/Psw_{t-1}). Thus, the pig crop starting on feed at time t is given as:

(25) $PIG_t = PIG((Phg^e_{t+2}/Psw_{t-1}), Isw_{t-1}, \alpha s)$.

Sow numbers depend on the expected return for breeding a sow, Rsw^e_t, piglets plus sow cull value, vs. the market value of a sow at time t, Psw_t. The expected return includes the market value of a sow plus the value of four litters of pigs. Another influence is the effect of disease on sow inventories, γs, $0 \leq \gamma s \leq 1$. Also, because inventory adjusts slowly to new desired levels, lagged inventory is included. Thus:

(26) $Isw_t = Isw(Rsw^e_t/Psw_{t-4}, \gamma s, Isw_{t-1})$.

As with cattle, swine at each stage have unique feed requirements. Per animal feed demands depend on the relative prices of wheat, coarse grains, and soybean meal. Forage and pasture are not used for hogs. Total demands are found by multiplying per animal feed use by the number of animals at each point in the production process. Let $ahg_{i,j,t}(Pw_t, Pg_t, Psm_t)$ be the per animal derived demand for feed i, i = w, g, sm, for market hogs in quarter t, stage j, where j = f for market hogs and j= p for pigs starting on feed.

Per unit use in each stage is a time-weighted average for two production substages linked to weight. Pigs starting on feed are comprised of two substages. Production substage 1 lasts about 40 days and brings the pig to a weight of 60 pounds. Substage 2 raises the weight to 120 pounds and covers about 45 days. Thus, feed demands for pigs starting on feed (births plus net imports), $Dhg_{i,p,t}$, are:

(27) $Dhg_{i,p,t} = ahg_{i,p,t}(Pw_t, Pg_t, Psm_t)*Shg_{i,p,t}$

where $Sgh_{i,j,t} = (PIG_t + Mhgfd_t - Xhgfd_t)$
for i = w, g, sm.

Market hogs are composed of the third and fourth substages. Substage 3 lasts for about 40 days, and the hog achieves a weight of 180 pounds. Substage 4 takes the animals to market weight of about 250 pounds and lasts about 40 days. Thus, for market animals at time t there are derived demands for each feed ingredient, $Dhg_{i,f,t}$:

(28) $Dhg_{i,f,t} = ahg_{i,f,t}(Pw_t, Pg_t, Psm_t)*Shg_t$,
i = w, g, sm.

Sows in a given quarter have different per unit feed demands. Denote per sow feed use of ingredient i as $asw_{i,t}(Pw_t, Pg_t, Psm_t)$. Thus, total feed use by sows at time t is, Dsw_{it}:

(29) $Dsw_{i,t} = asw_{i,t}(Pw_t, Pg_t, Psm_t)*Isw_t$.

Dairy Cattle

The structure of the dairy animal and feed allocation differs from other livestock feed allocations, since the model determines milk production using the zero-profit and sector-specific, factor-market-clearing conditions. Both milk output and dairy cattle being milked are determined simultaneously. The decision to determine milk output directly and convert that output into dairy cows reflects the way cost data are reported. Production costs for milk include the feed costs and not the heifer cost, whereas meat cost data include the animal but not the feed. Disease outbreaks are reflected in reduced milk output, which translates into reduced dairy cattle inventory. Thus, current milk output, qmk_t, determines the size of the dairy herd, Id_t. Further, because inventories of dairy cattle are slow to adjust, lagged inventory is included:

(30) $Id_t = Id(qmk_t, Id_{t-1})$.

Quarterly feeding for dairy cows is tied to the dairy herd. Dairy cows eat wheat, coarse grains, soybean meal, and forage and pasture. Denote the per cow use of feed ingredient i as $ad_{i,t}(Pw_t, Pg_t, Pfo_t, Psm_t)$. For quarter t, the demand for feed ingredient i by animals, $Dd_{i,t}$, is:

(31) $Dd_{i,t} = ad_{i,t}(Pw_t, Pg_t, Pfo_t, Psm_t)*Id_t$.

The replacement decision, Rd_t, depends on the expected return from milk production and calves over the next 16 quarters, Rmk^e_t, relative to the expected slaughter value of the animal in five quarters, Pc^e_{t+5}. Also, disease could exogenously cut replacement numbers by γd, $0 \leq \gamma d \leq 1$:

(32) $Rd_t = Rd(Rmk^e_t/Pc^e_{t+5}, \gamma d)$.

As replacement heifers move through the system, feed consumption varies. Let $ard_{i,t}(Pw_t, Pg_t, Pfo_t, Psm_t)$ be the per animal use of feedstuff i in quarter t. Total feed use for all replacement dairy heifers in quarter t for feedstuff i, $Drd_{i,t}$, is:

(33) $Drd_{i,t} = ard_{i,t}(Pw_t, Pg_t, Pfo_t, Psm_t)*Rd_t$.

Slaughter of dairy cattle at time t, Sdc_t, is determined by the inventory plus imports, Mdc_t, less dairy cattle exported, Xdc_t:

(34) $Sdc_t = Id_t + Mdc_t - Xdc_t$.

Dairy cattle trade is tied to the market price of cattle, a specific trade intervention, t_{dc}, and disease parameters that range from 0 to 1, γm_{dc} and γx_{dc}:

(35) $Mdc_t = Mdc(Pc_t - t_c)*\gamma m_{dc}$;

(36) $Xdc_t = Xdc(Pc_t - t_c)*\gamma x_{dc}$.

Poultry Meat

Due to its fast production process, poultry is relatively simple to model. For broilers, hatch-to-kill represents one quarter. To account for the time to hatch, lagged output is included, but with a very fast quarter-to-quarter adjustment. The meat model determines poultry meat production, qpm_t, via the zero-profit and sector-specific, factor-market-clearing conditions. Meat production is linked directly to bird numbers. Disease effects enter via the poultry meat production. Birds produced in a specific quarter, t, require a certain amount of feed of type i per ton $apm_{i,t}(Pw_t, Pg_t, Psm_t)$. Birds are assumed not to consume forage and pasture. Thus, total demand for feedstuff i, $Dpm_{i,t}$, is:

(37) $Dpm_{i,t} = apm_{i,t}(Pw_t, Pg_t, Psm_t)* qpm_t$,
$i = w, g, sm$.

Layers

The model also determines egg production, qe_t, using the zero-profit and sector-specific, factor-market-clearing conditions. The number of layers and feed use are known from egg production. Disease affects egg production (layer numbers). Layers respond more slowly than broilers, so lagged production is included with a stronger effect. With $al_{i,t}(Pw_t, Pg_t, Psm_t)$ the per unit use of feed, the total demand for feed of kind i, $Dl_{i,t}$, is:

(38) $Dl_{i,t} = al_{i,t}(Pw_t, Pg_t, Psm_t)*qe_t$,
$i = w, g, sm$.

Lambs and Sheep

The equations describing lambs and sheep are structured like those for beef cattle. Market lambs move through several distinct production stages. Lambs in the finishing stage at time t, $Slb_{f,t}$, move to slaughter. These animals were in the growing stage, $Slb_{g,t}$, in the previous quarter, so current slaughter lambs are those previous grower lambs adjusted for the effects of any disease outbreak, $\lambda lb_{,f}$, $0 \leq \lambda lb_{,f} \leq 1$. Current-period grower lambs were backgrounding lambs in the previous quarter, again adjusted for disease effects. Backgrounders in the current quarter, $Slb_{b,t}$, were the lamb crop in the previous quarter, $Slb_{g,t-1}$. Thus, the flow of market lambs is described by:

(39) $Slb_{f,t} = \lambda lb_{f,t}*Slb_{g,t-1}$

(40) $Slb_{g,t} = \lambda lb_{g,t}*Slb_{b,t-1}$

(41) $Slb_{b,t} = \lambda lb_{b,t}*Slb_{p,t}$.

The lamb crop is tied to the ewe inventory, Iew_t, and a disease shock:

(42) $Slb_{p,t} = Slb(Iew_t)*\lambda lb_{p,t}$.

Market equilibrium for slaughter lambs determines the price, Plb_t, by equating the demand for slaughter lambs, Dlb_t, to the supply of finished lambs plus net imports, $Mlb_t – Xlb_t$:

(43) $Dlb_t = Slb_{f,t} + Mlb_t – Xlb_t$.

Trade depends on the price of lambs, trade policy, t_{lb} , and the effects of any disease on trade. Those effects are described by parameters, m_{lb} and x_{lb}, respectively, ranging from 0 to 1, which reflect the restrictiveness of trade after an outbreak. The behavioral equations are:

(44) $Mlb_t = Mlb(Plb_t – t_{lb})*\gamma m_{lb}$,

(45) $Xlb_t = Xlb(Plb_t – t_{lb})*\gamma x_{lb}$.

Ewe inventory at time t depends on the expected value of holding a ewe for breeding, Rew^e_t, relative to the current market price of a ewe, Pew_t, ewe inventory one quarter previously, and a disease shock, λew_t. The expected return includes the slaughter value of a ewe plus the value of 2 lambs. Thus, the ewe inventory is given by:

(46) $Iew_t = Iew((Rew^e_t/Pew_t), Iew_{t-1})*\lambda ew_t$.

Inventories of replacement ewes, Ier_t, depend on the expected return to a ewe over the period t+4 to t+12, Rew^e_{t+4}, relative to the current market price of a slaughter ewe, the number of ewes one quarter previously, and a disease shock, λer_t:

(47) $Ier_t = Ier((Rew^e_{t+4}/Pew_t), Ier_{t-1})*\lambda er_t$.

Rams, Irm_t, are treated as exogenous.

Sheep and lambs use all feedstuffs: wheat, coarse grains, soybean meal, and forage and pasture. The mix of feeds varies by production stage. Let $alb_{i,j,t}$ be the use of feed i, i = w, g, sm, f, by an individual lamb at production stage j, j = f, g, b, p, at time t. With constant returns to scale, the per animal feed demands depend only on feedstuff prices. Consequently, the total feed demands, $Dlb_{i,j,t}$, are:

(48) $Dlb_{i,j,t} = alb_{i,j,t}(Pw_t, Pg_t, Psm_t, Pfo_t)*Slb_{j,t}$
where i = w, g, sm, fo, and j = f, g, b, p.

Ewes, replacements, and rams have a similar structure. Let $aew_{i,t}$ be the per ewe use of feed i, with $aer_{i,t}$ and $arm_{i,t}$ the same for replacements and rams, respectively. These depend on feedstuff prices and season. Thus, the total demand for feed i by ewes, $Dew_{i,t}$, is:

(49) $Dew_{i,t} = aew_{i,t}(Pw_t, Pg_t, Psm_t, Pfo_t)*Iew_t$
for i = w, g, sm, fo.

The feed demands for replacements, $Der_{i,t}$, are:

(50) $Der_{i,t} = aer_{i,t}(Pw_t, Pg_t, Psm_t, Pfo_t)*Ier_t$,
for i = w, g, sm, fo.

The feed demands by rams, $Drm_{i,t}$, are:

(51) $Drm_{i,t} = arm_{i,t}(Pw_t, Pg_t, Psm_t, Pfo_t)*Irm_t$,
for i = w, g, sm, fo.

Crops

The previous discussion identified demands for feedstuffs. The crop agriculture relationships are now developed. Crops included are wheat, coarse grains, soybeans, rice, and forage and pasture. In addition to the feedstuff demands, there are demands arising from final (retail) demands. The focus here is the supply side. Crop production occurs at set times and then becomes carryin stock in subsequent quarters until a new crop is harvested. Another key feature is that due to the dynamics, production decisions are made well before harvest, based on expectations of returns for the crops. Finally, except for forage and pasture, all of the crops included in the model are program crops. This means the influence of the various U.S. Government price and income supports must be incorporated.

Crop production (acreage) decisions are made quarters ahead of production because input supplies must be ordered and land leases arranged. The acreage allocation is based on expected returns for crops at harvest, with expected returns being the previous harvest prices plus appropriate government payments. The computations are done in quarter 1 so that an acreage allocation consistent with one crop cycle can be imposed. Since there are both winter and spring crops in the model, this is a simplification of the actual decision process.

Soybeans and rice are spring crops. They are planted in the second quarter of the current year and harvested in quarters 3 (rice) or 4 (soybeans). Coarse grains are an aggregate of crops: corn, sorghum, millet, barley, rye, and oats. Coarse grains are dominated by corn and sorghum, which are planted in quarter 2 and harvested in quarter 4. Oats and rye are minor crops, harvested in the third quarter. Barley, also a minor crop, consists of both winter and spring barley, which are assumed to be harvested in quarters 2 and 3, based on earlier production decisions.

Wheat poses a larger problem as a major crop with both spring and winter production. Spring wheat is harvested in quarter 3 after being planted in quarter 2. Winter wheat is planted in the fourth quarter of the previous year and harvested beginning in the second quarter of the current year (May, June, and July). For this model the assumption is that winter wheat is harvested in quarter 2. The acreage (production) decision for that harvest is assumed to be made in the first quarter of the year, based on returns to second-quarter wheat in the previous year, to create a consistent use of land. This is because the decision to plant winter wheat the previous fall requires arranging inputs earlier in the year and constrains cropping decisions in the spring.

Modeling of forage and pasture poses problems similar to wheat. Production occurs in quarters 2 and 3. Forage and pasture acreage is assumed to be determined in quarter 1, based on the quarter 2 and 3 prices of the previous year.

To determine crop production, return to the structure outlined at the beginning of this section. Crop production for quarter t is based on the vector of expected crop returns calculated in the first quarter, $\mathbf{P^e_1}$, via zero-profit conditions:

$$(52)\ Ct(\mathbf{W}, \mathbf{R^e}, \boldsymbol{\tau}) = \mathbf{P^e_1},$$

where $\mathbf{R^e}$ is the vector of expected returns to physical and human capital and $\mathbf{P^e_1}$ is the vector of expected returns for crops in the first quarter of the year. Since the mobile input is in perfectly elastic supply, **W** is exogenous. The return to land, $\boldsymbol{\tau}$, captures the negotiation process between farmer and landlord for land rent in the upcoming crop season. Thus, the expected return to physical and human capital, $\mathbf{R^e}$, is determined by the expected zero-profit condition.

Expected returns for crops consist of several parts and vary depending on market conditions. The price expected in quarter 1 is that prevailing in the harvest quarter of the previous year. The return reflects U.S. Government payments. There are several payments to include, and there is debate about how they affect production—the decoupling issue (Goodwin and Mishra). If the loan rate (LR) exceeds the quarterly market price, the farmer is assumed to receive loan deficiency payments (LDPs) equal to the difference. The payments are made on the full amount of production. Direct payment rates (DPs) are established by law. Total payments are the rate multiplied by 85 percent multiplied by program yield and base area. Additionally, the 2002 Farm Act provides for countercyclical payments (CCPs), calculated from an announced target price (TP). The payment rate is the difference between the target price, less any direct payment, and the market price when the market price is above the loan rate. If LDPs are paid, they are not adjusted by the .85 used in the CCP adjustment, but instead, the full LDP is added to the market price. The payments are 85 percent of the payment rate times the eligible production, which is program yield, times crop base acreage. The expected return is the expected price on the previous crop plus CCP payments, LDPs, and direct payments.

Loan deficiency payments are coupled payments. A critical issue is whether direct payments and CCPs are decoupled or not. Returns to human and physical capital and to land cannot be adequately modeled without including these payments, so they are reflected in the model and affect the dynamics of the model solutions. The payments are modeled to affect relative per acre returns among program crops. Since forage and pasture are not program crops, there is no direct price adjustment, but there is a relative price effect.

Sector-specific, factor-market-clearing conditions, using expected rent and factor prices in quarter 1, determine crop output for quarter t:

$$(53)\ \mathbf{a_K}(\mathbf{W}, \mathbf{R^e}, \boldsymbol{\tau})^*\mathbf{Q_t} = \mathbf{K}_1.$$

Land is mobile among the crops. Its return is determined in quarter 1 by the demand and supply for land for the upcoming crops in period t:

(54) $\mathbf{at(W, R^e, \tau)*Q_t = T}$,
where T is total land available for crops in t.

While crop output is determined based on the expected returns to sector-specific factors, actual returns to the sector-specific factors, $\mathbf{R_t}$, can differ from expected returns because actual returns to crop production differ from expected returns. The actual market prices, $\mathbf{Pm_t}$, are determined in the market-clearing identities. Once the crop market prices are known, the LDP and CCP payment rates and total payments can be calculated for the crop produced at time t. The actual return to the program crop, $\mathbf{P_t}$, is found with the addition of the payments:

(55) $\mathbf{P_t} = \mathbf{Pm_t} + 0.85*\mathbf{DP}*(\mathbf{y}*\mathbf{A})/\mathbf{Q} + \mathbf{Z_1} + \mathbf{Z_2}$,

$$\text{where } \mathbf{Z_1} = \begin{cases} 0.85*(\mathbf{TP_t} - \mathbf{Pm_t})(\mathbf{y}*\mathbf{A})/\mathbf{Q}, \text{ if } \mathbf{Pm_t} < \mathbf{TP_t}, \\ \mathbf{0}, \text{ if } \mathbf{Pm_t} > \mathbf{TP_t} \end{cases}$$

$$\mathbf{Z_2} = \begin{cases} (\mathbf{LR_t} - \mathbf{Pm_t}) \text{ if } \mathbf{Pm_t} < \mathbf{LR_t}, \\ \mathbf{0}, \text{ if } \mathbf{Pm_t} > \mathbf{LR_t} \end{cases}$$

where **y** is a vector of program yields established by rules set by the U.S. Government, **A** is a vector of base acreages, and **Q** is a vector of quarterly production.

The return to forage and pasture is the market price, since there is no program. Thus, the zero-profit condition determining the actual return to physical and human capital in period t, $\mathbf{R_t}$, is:

(56) $\mathbf{C}(\mathbf{W}, \mathbf{R_t}, \tau) = \mathbf{P_t}$.

Supply in a given quarter is any production in that quarter, $\mathbf{Q_t}$, plus carryin stocks, $\mathbf{I_{t-1}}$. To identify carryin stocks, carryover stock must be identified. Carryin stocks are the previous period's carryover stock, $\mathbf{I_{t-1}}$, so defining carryover stocks with behavioral equations completes the supply side supply of crop i in period t. Carryout stocks are determined by a price-speculative motive, $\mathbf{Pm^e_{t+1}/Pm_t}$:

(57) $\mathbf{I_t} = \mathbf{I}(\mathbf{Pm^e_{t+1}/Pm_t})$.

Soybean Complex

The soybean complex is included for two reasons. First, soybean meal is a major feedstuff, and its use is affected by any disease outbreak. Second, soybeans compete with other crops for acreage. Since the supply describes soybean production and the demands are for soybean meal for feed and soybean oil for food, the crushing of soybeans into the joint products, soybean meal and soybean oil, must be modeled. This is done by specifying a derived demand for soybeans for crushing, Dsb_t, which is a function of the current period crushing margin, SPD_t:

(58) $Dsb_t = Dsb(SPD_t)$.

The crushing margin is the value of the joint products, given by their yields multiplied by their prices, Psm and Pso, less the price of soybeans, Psb.

Let β_m and β_o be the yields of soybean meal and soybean oil from a ton of soybeans. The margin is defined as:

(59) $SPD_t = \beta_m * Psm_t + \beta_o * Pso_t - Psb_t$.

Outputs of soybean meal, qsm, and soybean oil, qso, are the yields multiplied by the crush:

(60) $qsm_t = \beta m * Dsb_t$,

(61) $qso_t = \beta o * Dsb_t$.

Closure

Model closure requires domestic and international market-clearing relationships for quantities and prices. Exports, $\mathbf{X}_t$, and imports, $\mathbf{M}_t$, depend on prices and trade interventions, and in some cases on the disease outbreak. For many agricultural goods, the United States is an exporter and does not intervene in the market. Let **tx** be a vector of specific trade interventions. To allow effects from disease-related trade restrictions, like a ban on beef exports, define **λx** as a vector of parameters ranging from 0 to 1, where 0 implies an export ban and 1 is no restriction. So the excess demand faced by the United States is:

(62) $\mathbf{X}_t = \mathbf{X}(\mathbf{Pm}_t - \mathbf{tx}) * \boldsymbol{\lambda}\mathbf{x}$.

While many agricultural goods are imported into the United States without restriction, beef and dairy products are subject to tariff-rate quotas, TRQs. A tariff-rate quota is a stepped tariff where import volumes below the quota require payment of a lower tariff than import volumes above the quota. To illustrate, the below-quota tariff for beef is $0.04 per kilogram ($88.18 per ton), while the over-quota tariff is 26 percent. Let beef imports be Mb_t, the U.S. domestic beef price be Pb_t, and the world beef price be PWb_t. Thus, the policy is modeled as:

(63) If $Mb_t < Quota$, then $Pb_t = PWb_t + 88.18$,
If $Mb_t > Quota$, then $Pb_t = PWb_t*(1+0.26)$,
If $Mb_t = Quota$, then Pb_t clears the domestic market-given Quota.

To facilitate model solution, it is assumed that the quotas are not filled, and the below-quota specific intervention applies, **tm**. Quota underfill seems to be more common for U.S. beef imports than quota overfill. When an intervention is applied, it is deducted from the U.S. domestic price so that trade reacts to the "world" or border price. Disease-related trade restrictions are allowed through a parameter, **λm**.

The remaining imports are explained by an excess supply to the United States:

(64) $\mathbf{M}_t = \mathbf{M}(\mathbf{Pm}_t - \mathbf{tm}) * \boldsymbol{\lambda}\mathbf{m}$.

Market-clearing identities can be written using the matrix notation:

(65) $\mathbf{M}_t = \mathbf{DF}_t + \mathbf{DD}_t + \mathbf{X}_t + \mathbf{I}_t - \mathbf{Q}_t - \mathbf{I}_{t-1}$,

where **DD** is column vector of derived demands for feedstuffs and animals.

Completing the model requires vertically linking the prices. This improves the numerical accounting of the impacts, but does not affect model response to shocks. There are three levels to prices: farm prices for crops and livestock, **Pm**, wholesale prices for meats, milk, and eggs, **PM**, and retail prices for all final goods, **PR**. These levels are linked by marketing margins calculated by the Economic Research Service of the U.S. Department of Agriculture (ERS). The farm-to-wholesale margin is denoted SPDW, while the wholesale-to-retail margin is denoted SPDR. Thus, price linkage equations are:

(66) $\mathbf{PM}_t = \mathbf{Pm}_t + \mathbf{SPDW}_t$,

(67) $\mathbf{PR}_t = \mathbf{PM}_t + \mathbf{SPDR}_t$.

Differential Transformation of the Conceptual Model

A numerical solution of the integrated epidemiological and economic agricultural sector model is facilitated by a total logarithmic differential version of the equations presented in the preceding section. The logarithmic differential version is advantageous because the differential version is driven by elasticities, which are easier to obtain than specific functional forms and are also more intuitive than partial derivatives. The logarithmic differential version can also be applied to observed historical data, avoiding the need to forecast future exogenous variable values. The base data can also be updated as new values become available.

Final Consumer Demand

The final demand system in general functional form is given by equations (1) and (2). Substituting equation (1) into equation (2) and logarithmically differentiating gives a 10-equation system:

(68) $\text{dln}(\mathbf{DF_t}) = \text{dln}(\text{pop}_t) + \text{dln}(\boldsymbol{\alpha_t}) + \boldsymbol{\varepsilon}^*\text{dln}(\mathbf{PR_t}) + \boldsymbol{\varepsilon}_y\text{dln}(\mathbf{y})$,

where $\boldsymbol{\varepsilon}$ is a 10 X 10 matrix of own- and cross-price elasticities and $\boldsymbol{\varepsilon}_y$ is a vector of income elasticities.

Supplies of Final Goods

Meat, Milk, and Egg Production

Meat, milk, and egg production are described by the zero-profit equations (3) and the sector-specific, factor-market-clearing conditions (4). There are six of each type. Totally differentiating the zero-profit conditions at time t, applying the envelope property, and with quantity normalization on the unit isoquant, the percentage change in the wholesale price is a linear combination of the factor-price changes. Let $\boldsymbol{\Theta}$ be the 6x13 matrix of unit revenue shares and $\boldsymbol{\Omega}^T$ the 13x1 column vector of factor-price changes, $\boldsymbol{\Omega} = [\text{dln}\mathbf{W_t}, \text{dln}\mathbf{PA_t}, \text{dln}\mathbf{R_t}]$. Total differentiation of equation (3) gives:

(69) $\boldsymbol{\Theta}^*\boldsymbol{\Omega}^T = \text{dln}(\mathbf{PM_t})$.

With the mobile factor price, **W**, exogenous, the mobile factor-market-clearing identity is dropped so equation (4) can be partitioned into two sets of equations. Define **QM** as a 6x1 column vector of beef, pork, poultry meat, lamb and sheep meat, milk, and egg production. Let **AK** be the 6x1 column vector of per unit use of physical and human capital. Thus, part of equation (4) can be written in differential form:

(70) $\mathrm{dln}(\mathbf{QM_t}) + \mathrm{dln}(\mathbf{AK_t}) = \mathrm{dln}(\mathbf{K_t})$.

The second part of equation (4) gives the derived demand for animals for slaughter—beef cattle, swine, lambs and sheep, broilers, and for production inventory—dairy cows and layers. The 6x1 column vector, **AA**, gives per unit derived demands, and **DA** gives the total derived demand. Thus, the factor demands are:

(71) $\mathrm{dln}(\mathbf{DA_t}) = \mathrm{dln}(\mathbf{QM_t}) + \mathrm{dln}(\mathbf{AA_t})$.

Completing this part of the model requires specifying the changes in per unit factor uses. Let **AW** be a 6x1 column vector of per unit demand for the mobile factor. Logarithmic differentiation links changes in the ratio of per unit factor use to changes in factor prices via the matrix of Morishima elasticities of substitution between mobile factors and capital, $\boldsymbol{\sigma_w}$, and between animals and capital, $\boldsymbol{\sigma_a}$, under constant returns to scale (e.g., Chambers, 1988, p. 96):

(72) $\mathrm{dln}(\mathbf{AW_t}) - \mathrm{dln}(\mathbf{AK_t}) = -\boldsymbol{\sigma_w}*(\mathrm{dln}(\mathbf{W_t}) - \mathrm{dln}(\mathbf{R_t}))$,

(73) $\mathrm{dln}(\mathbf{AA_t}) - \mathrm{dln}(\mathbf{AK_t}) = -\boldsymbol{\sigma_a}*(\mathrm{dln}(\mathbf{PA_t}) - \mathrm{dln}(\mathbf{R_t}))$.

Also it can be shown that for movements around the unit isoquant:

(74) $\boldsymbol{\Theta}*\mathrm{dln}(\mathbf{A^T}) = 0$,
where $\mathbf{A} = [\mathbf{AW_t}, \mathbf{AA_t}, \mathbf{AK_t}]$.

Animal Inventories

Differentiation of the animal inventory is straightforward. One element of $\mathbf{DA_t}$ is the demand for cattle for slaughter at time t, Dc_t. Equation (5) for beef cattle becomes:

(75) $Dc_t*\mathrm{dln}(Dc_t) = Sc_{f,t}*\mathrm{dln}(Sc_{f,t}) + Sdc_t*\mathrm{dln}(Sdc_t) + Mc_t*\mathrm{dln}(Mc_t)$
$- Xc_t*\mathrm{dln}(Xc_t)$.

Cattle slaughtered at time t depend on the flow of animals through the different stages of production, as given by equations (6) through (9). Differentiating equations (6) through (9) gives:

(76) $\mathrm{dln}(Sc_{f,t}) = \mathrm{dln}(Sc_{g,t-1}) + \mathrm{dln}(\lambda_{c,f})$,

(77) $\mathrm{dln}(Sc_{g,t}) = \mathrm{dln}(Sc_{b,t-1}) + \mathrm{dln}(\lambda_{c,g})$,

(78) $\mathrm{dln}(Sc_{b,t}) = \mathrm{dln}(Sc_{w,t-1}) + \mathrm{dln}(\lambda_{c,b})$,

(79) $\mathrm{dln}(Sc_{w,t}) = \mathrm{dln}(Sc_{p,t-1}) + \mathrm{dln}(\lambda_{c,w})$.

Calves entering production depends on cow inventories, equation (10), which, after some manipulation, becomes:

(80) $dln(Sc_{p,t}) = \eta c*dln(Ic_t) + \eta_{\alpha c}*dln(\lambda c_{c,p})$,

where in equation (80) and in what follows, η_{ij} is the percent response of i with respect to a 1-percent change in j (i.e., elasticities). Cow inventory, equation (14), depends on breeding and replacement decisions:

(81) $dln(Ic_t) = \eta_{Pe}*(dln(Rc^e_t) - dln(Pc_t)) + \eta_{hc}*dln(Ic_{t-1}) + \eta_{\gamma}*dln(\gamma c)$.

The change in replacement heifers is determined by the replacement decision based on expected relative prices:

(82) $dln(Hc_t) = \eta_{hp}*(dln(Pc^e_{t+16}) – dln(Pc^e_{t+5})) + \eta_{\lambda h}*dln(\lambda h)$.

Swine follow the same pattern. The demand for market hogs, Dhg_t, is one element in **DA**. The change in demand for market hogs equals the changes in domestic supply plus imports less exports:

(83) $Dhg_t*dln(Dhg_t) = Shg_t*dln(Shg_t) + Mhgs_t*dln(Mhgs_t)$
$– Xhgs_t*dln(Xhgs_t)$.

The supply of market hogs equals feeder pig imports and farrowings, adjusted for deaths, less feeder pig exports:

(84) $Shg_t*dln(Shg_t) = Mhgfd_{t-1}*dln(Mhgfd_{t-1}) + \lambda s*PIG_{t-2}*(dln(\lambda s) +$
$dln(PIG_{t-2})) – Xhgfd_{t-1}*dln(Xghfd_{t-1})$.

The change in the pig crop depends on the expected value of market hogs in two quarters, relative to the market value of a sow last quarter and the sow inventory:

(85) $PIG_t*dln(PIG_t) = \eta_{phg}* (dln(Phg^e_{t+2}) – dln(Psw_{t-1})) + \eta_{PIG}*(dlnIsw_t) +$
$\eta_{\alpha s}*dln(\alpha s)$.

Sow inventory depends on the expected relative returns:

(86) $dln(Isw_t) = \eta_{IS}*(dln(Rsw^e_t) – dln(Psw_{t-1})) + \eta_{\gamma s}*dln(\gamma s) + \eta_{sw}*dln(Isw_{t-1})$.

Milk production is determined by disease impacts on milk output as reflected in equation (30), due to the way cost data for milk are reported. Based on changes in milk output, the change in dairy cow inventory is determined:

(87) $dln(Id_t) = \eta_{mk}*dln(qmk_t) + \eta_{Id}*dln(Id_{t-1})$.

The breeding/replacement decision depends on relative expected returns:

(88) $dln(Rd_t) = \eta_{Rd}*(dln(Rmk^e_t) – dln(Pc^e_{t+5})) + \eta_{\gamma d}*dln(\gamma d)$.

Cull of dairy cows, Sdc, is determined by the residual of the inventory plus imports less exports:

(89) $Sdc_t*dln(Sdc_t) = Id_t*dln(Id_t) + Mdc_t*dln(Mdc_t) – Xdc_t*dln(Xdc_t)$.

Lamb and sheep inventory is described by equations (46) and (47). Differentiating equation (46) gives the change in ewe inventory:

(90) $dln(Iew_t) = \eta ew_p*(dln(Rew^e_t - dln(Pew_t)) + \eta ew_I*dln(Iew_{t-1}) + dln(\lambda ew_t)$.

The change in replacement ewes comes from differentiating equation (47):

(91) $dln(Ier_t) = \eta er_p*(dln(Rew^e_{t+4}) - dln(Pew_t)) + \eta er_I*dln(Ier_{t-1}) + dln(\lambda er_t)$.

Once ewe inventory is determined, the flow of market lambs can be found, as in equations (39) through (42). Equation (42) gives the slaughter lamb crop, which, when differentiated, becomes:

(92) $dln(Slb_{p,t}) = \eta lb_I*dln(Iew_t) + dln(\lambda lb_{p,t})$.

Subsequently, lambs move through the remaining stages of production:

(93) $dln(Slb_{b,t}) = dln(Slb_{p,t-1}) + dln(\lambda lb_{b,t})$,

(94) $dln(Slb_{g,t}) = dln(Slb_{b,t-1}) + dln(\lambda lb_{g,t})$,

(95) $dln(Slb_{f,t}) = dln(Slb_{f,t-1}) + dln(\lambda lb_{f,t})$.

With the change in supply of finished slaughter lambs determined, the change in the market price for lambs is determined using the differential of the market-clearing identity, equation (43):

(96) $dln(Dlb_t) = dln(Slb_{f,t}) + dln(Mlb_t) - dln(Xlb_t)$.

Feed Demands

The feed demands reflect the age distribution and flow of animals. Beef cattle generate a large set of feed demands. Finished beef cattle slaughtered in period t are the outcome of a process beginning five quarters previously. Thus, for market cattle there are five temporal demands for each feed ingredient—wheat, coarse grains, soybean meal, forage, and pasture. Let subscript i denote the feed ingredient (i = w, g, sm, fo) and j (j = f, g, b, w, p) denote the stage. Recall that $as_{i,j,t}$ is the per animal feed use at time t. This follows equation (13), and totally differentiating it gives:

(97) $dln(DSc_{i,j,t}) = dln(as_{i,j,t}) + dln(Sc_{j,t})$,
i = w, g, sm, fo, and j = f, g, b, w, p.

Because the per unit feed demands are responsive to changes in relative feed prices, the percentage changes in the derived demands for feeds use Morishima elasticities of substitution, $\sigma_{i,g,c}$, where i gives feedstuff, wheat, soybean meal, or forage/pasture, g indicates coarse grains, and c indicates beef cattle:

(98) $dln(a_{i,c,t}) - dln(a_{g,c,t}) = -\sigma_{i,g,c}*(dln(P_{i,t}) - dln(P_{g,t}))$,
i = w, sm, fo,

(99) $\sum_i \theta_{i,c} * \mathrm{dln}(a_{i,c,t}) = 0$,
i = w, g, sm, fo.

The cow inventory at time t also has unique feed demands, as in equation (15). Thus, the change in feed demand for feedstuff i by cows at time t is:

(100) $\mathrm{dln}(Dc_{i,t}) = \mathrm{dln}(ac_{i,t}) + \mathrm{dln}(Ic_t)$,
i = w, g, sm, fo.

Changes in relative prices alter the per cow mix of feedstuff according to the Morishima elasticities of substitution:

(101) $\mathrm{dln}(ac_{i,t}) – \mathrm{dln}(ac_{g,t}) = - \sigma_{i,g,c} * (\mathrm{dln}(P_{i,t}) – \mathrm{dln}(P_{g,t}))$,
i = w, sm, fo,

(102) $\sum_i \theta_{i,c} * \mathrm{dln}(ac_{i,t}) = 0$,
i = w, g, sm, fo.

Feed use by replacement heifers at time t varies by per unit use, $ah_{i,k}$, and hence by feedstuff prices, changes in replacement heifer numbers:

(103) $\mathrm{dln}(Dh_{i,t}) = \mathrm{dln}(ah_{i,t}) + \mathrm{dln}(Hc_t)$,
i = w, g, sm, fo,

(104) $\mathrm{dln}(ah_{i,t}) – \mathrm{dln}(ah_{g,t}) = - \sigma_{i,g,c} * (\mathrm{dln}(P_{i,t}) – \mathrm{dln}(P_{g,t}))$,
i = w, sm, fo,

(105) $\sum_i \theta_{i,c} * \mathrm{dln}(ah_{i,t}) = 0$,
i = w, g, sm, fo.

Feed use by bulls for ingredient i at time t is similar:

(106) $\mathrm{dln}(Db_{i,t}) = \mathrm{dln}(ab_{i,t}) + \mathrm{dln}(Bc_t)$,
i = w, g, sm, fo,

(107) $\mathrm{dln}(ab_{i,t}) – \mathrm{dln}(ab_{g,t}) = - \sigma_{i,g,c} * (\mathrm{dln}(P_{i,t}) – \mathrm{dln}(P_{g,t}))$,
i = w, sm, fo,

(108) $\sum_i \theta_{i,c} * \mathrm{dln}(ab_{i,t}) = 0$,
i = w, g, sm, fo.

Slaughter hogs go through two cycles per quarter. At time t, there is one group of hogs ready for slaughter, j = f, and another just beginning the process, j = p. The change in demand for feedstuff i by hogs ready for slaughter depends on the change in per hog use, the disease effects, and any changes in the supply of market hogs:

(109) $\mathrm{dln}(Dhg_{i,j,t}) = \mathrm{dln}(ahg_{i,j,t}) + \mathrm{dln}(Shg_{j,t})$,
i = w, g, sm,

Changes in per unit feed use are linked to change in feed prices:

(110) $\mathrm{dln}(ahg_{i,j,t}) – \mathrm{dln}(adhg_{i,g,t}) = - \sigma_{i,g,s} * (\mathrm{dln}(P_{i,t}) – \mathrm{dln}(P_{g,t}))$,
i = w, sm,

(111) $\sum_i \theta_{i,s}$*$dln(ahg_{i,j,t}) = 0$,
i = w, g, sm.

The changes in the demands for feed ingredients for breeding hogs take the form:

(112) $dln(Dsw_{i,t}) = dln(asw_{i,t}) + dln(Isw_t)$,
i = w, g, sm,

(113) $dln(asw_{i,t}) = -\sigma_{i,g,s}*(dln(P_{i,t}) - dln(P_{g,t}))$,
i = w, sm,

(114) $\sum_i \theta_{i,s}*dln(asw_{i,t}) = 0$,
i = w, g, sm.

Changes in feed demand for ingredient i by dairy cows depend on a change in the per unit demand, driven by feed price changes and changes in inventory:

(115) $dln(Dd_{i,t}) = dln(ad_{i,t}) + dln(Id_t)$,
i = w, g, sm, fo,

(116) $dln(ad_{i,j,t}) - dln(ad_{g,t}) = -\sigma_{i,g,d}*(dln(P_{i,t}) - dln(P_{g,t}))$,
i = w, sm, fo,

(117) $\sum_i \theta_{i,d}*dln(ad_{i,t}) = 0$,
i = w, g, sm, fo.

Replacement dairy heifers also generate feed demands:

(118) $dln(Drd_{i,t}) = dln(ard_{i,t}) + dln(Rd_t)$,
i = w, g, sm, fo,

(119) $dln(ard_{i,t}) - dln(ard_{g,t}) = -\sigma_{i,g,d}*(dln(P_{i,t}) - dln(P_{g,t}))$,
i = w, sm, fo,

(120) $\sum_i \theta_{i,d}*dln(ard_{i,t}) = 0$,
i = w, g, sm, fo.

Given their shorter production cycle, changes in demands for feed ingredients for broilers and layers are straightforward:

(121) $dln(Dpm_{i,t}) = dln(apm_{i,t}) + dln(qpm_t)$,
i = w, g, sm,

(122) $dln(apm_{i,t}) - dln(apm_{g,t}) = -\sigma_{i,g,pm}*(dln(P_{i,t}) - dln(P_{g,t}))$,
i = w, sm,

(123) $\sum_i \theta_{i,pm}*dln(apm_{i,t}) = 0$,
i = w, g, sm.

(124) $dln(Dl_{i,t}) = dln(al_{i,t}) + dln(qe_t)$,
i = w, g, sm,

(125) $dln(al_{i,t}) - dln(al_{g,t}) = - \sigma_{i,g,l}*(dln(P_{i,t}) - dln(P_{g,t}))$,
i = w, sm,

(126) $\sum_i \theta_{i,l}*dln(al_{i,t}) = 0$,
i = w, g, sm.

Feed demand by lambs and sheep arise from market lambs, ewe inventory, and replacement ewes. For market lambs, there are four stages of production, denoted by j, j = f, g, b, p. The change in the demand for feed ingredient i by market lambs at stage j is:

(127) $dln(Dlb_{i,j,t}) = dln(alb_{i,j,t}) + dln(Slb_{j,t})$,
i = w, g, sm, fo,

(128) $dln(alb_{i,j,t}) - dln(alb_{g,j,t}) = - \sigma_{i,g,lb}*(dln(P_{i,t}) - dln(P_{g,t}))$,
i = w, sm, fo,

(129) $\sum_i \theta_{i,lb}*dln(alb_{i,j,t}) = 0$,
i = w, g, sm, fo, and j = f, g, sm, fo.

Ewe inventory, replacement ewes, and rams have a similar structure. Differentiating equation (49), feed demand by ewes, gives:

(130) $dln(Dew_{i,t}) = dln(aew_{i,t}) + dln(Iew_t)$,
i = w, g, sm, fo,

(131) $dln(aew_{i,t}) - dln(aew_{g,t}) = - \sigma_{i,g,lb}*(dln(P_{i,t}) - dln(P_{g,t}))$,
i = w, sm, fo,

(132) $\sum_i \theta_{i,lb}*dln(aew_{i,t}) = 0$,
i = w, g, sm, fo.

Feed demands by replacements are expressed by equation (50). Differentiation gives:

(133) $dln(Der_{i,t}) = dln(aer_{i,t}) + dln(Ier_t)$,
i = w, g, sm, fo,

(134) $dln(aer_{i,t}) - dln(aer_{g,t}) = - \sigma_{i,g,lb}*(dln(P_{i,t}) - dln(P_{g,t}))$,
i = w, sm, fo,

(135) $\sum_i \theta_{i,lb}*dln(aer_{i,t}) = 0$,
i = w, g, sm, fo.

Differentiation of the feed demands by rams has the same pattern:

(136) $dln(Drm_{i,t}) = dln(arm_{i,t}) + dln(Irm_t)$,
i = w, g, sm, fo,

(137) $dln(arm_{i,t}) - dln(arm_{g,t}) = - \sigma_{i,g,lb}*(dln(P_{i,t}) - dln(Pg,t))$,
i = w, sm, fo,

(138) $\sum_i \theta_{i,lb}*dln(arm_{i,t}) = 0$,
i = w, g, sm, fo.

Crop Production

The next component of the model consists of logarithmic differentiation of the crop production structure. Differentiating equation (52) determines the change in expected returns for crop i:

(139) $\theta_{L_i}*dln(W_i) + \theta_{K_i}*dln(R*_i) + \theta_{T_i}*dln(\tau_i) = dln(P*_i)$,
i = w, g, r, sb, fo.

Differentiating the sector-specific, factor-market-clearing conditions for crop i, equation (53) determines the changes in production of crop i:

(140) $dln(a_{K_{i,t}}) + dln(q_{i,t}) = dln(K_i)$,
i = w, g, r, sb, fo,

(141) $dln(a_{L_{i,t}}) – dln(a_{K_{i,t}}) = - \sigma_{L,K_i}(dln(W_i) – dln(R*_i))$,
i = w, g, r, sb, fo,

(142) $dln(a_{T_i,t}) – dln(a_{K_i,t}) = - \sigma_{T,K_i}*(dln(\tau) – dln(R*_i))$,
i = w, g, r, sb, fo,

(143) $\theta_{L_i}*dln(a_{L_i,t}) + \theta_{K_i}*dln(a_{K_i,t}) + \theta_{T_i}*dln(a_{T_i,t}) = 0$,
i = w, g, r, sb, fo.

Factoring in the change in land allocation, which determines the land rent, differentiating equation (54), and letting λ_{Ti} be the share of land used by crop i, yields:

(144) $\sum_i \lambda_{T_i}*(dln(q_{i,t}) + dln(a_{T_{i,t}})) = dln(T_t)$,
i = w, g, r, sb, fo.

The logarithmic differential of actual returns to crop i,
i = w, g, r, sb, fo, is:

(145) $dln(P_{i,t}) = (Pm_{i,t}/P_{i,t})*dln(Pm_{i,t}) + (0.85*y_i*A_i/(q_i*P_{i,t}))*(dln(DP_i) + dln(y_i) + dln(A_i) – dln(q_i) + Z_{1,i,t}*dln(Z_{1,i,t}) + Z_{2,i,t}*dln(Z_{2,i,t})$,

where

$$Z_{1i,t}*dln(Z_{1i,t}) = \begin{cases} [0.85*y_i*A_i/q_i]*[dln(y_i) + dln(A_i) – dln(q_i) + (TP_{i,t}/(TP_{i,t} – Pm_{i,t}))*dln(TP_{i,t}) – (Pm_{i,t}/(TP_{i,t} – Pm_{i,t})*dln(Pm_{i,t})], & \text{when } Pm_{i,t} < TP_{i,t}, \text{ or} \\ 0, & \text{when } Pm_{i,t} \geq TP_{i,t}, \end{cases}$$

$$Z_{2,i,t}*dln(Z_{2,i,t}) = \begin{cases} [LR_{i,t}/(LR_{i,t} – Pm_{i,t})]*dln(LR_{i,t}) – [Pm_{i,t}/(LR_{i,t} – Pm_{i,t})] *dln(Pm_{i,t}), & \text{when } Pm_{i,t} < LR_{i,t}, \\ 0, & \text{when } Pm_i \geq LR_i. \end{cases}$$

The changes in the actual returns to sector-specific factors for crops are found by differentiating equation (56) and using the actual return as determined above:

(146) $\theta_{L_i}*\text{dln}(W_i) + \theta_{K_i}*\text{dln}(R_{i,t}) + \theta_{T_i}*\text{dln}(\tau) = \text{dln}(P_{i,t})$.

Total crop supply in a quarter includes carryin stocks from the previous quarter. Ending stocks are given by equation (57). Totally differentiating that equation gives:

(147) $\text{dln}(I_{i,t}) = \varepsilon_p*(\text{dln}(P*_{i,t+1}) - \text{dln}(Pm_{i,t}))$,
i = w, g, r, sb, fo,

where ε_p is the elasticity of expected returns to price speculation.

Soybean Complex

Soybean crushing depends on the margin, which depends on the prices of soybean meal, soybean oil, and soybeans. Assuming meal and oil yields are constant, differentiating the crush demand and the margin identity gives:

(148) $\text{dln}(Dsbt) = \varepsilon_m*\text{dln}(SPD_t)$,

(149) $\text{dln}(SPD_t) = (Psm_t/SPD_t)*\text{dln}(Psm_t) + (Pso_t/SPD_t)*\text{dln}(Pso_t) - (Psb_t/SPD_t)*\text{dln}(Psb_t)$.

The changes in supplies of meal and oil are obtained from changes in the crush:

(150) $\text{dln}(qsm_t) = \text{dln}(Dsb_t)$,

(151) $\text{dln}(qso_t) = \text{dln}(Dsb_t)$.

Closure

Closure requires logarithmically differentiating the remaining equations. The excess demand and excess supply equations include trade policy interventions. Since several commodities do not have trade interventions, the logarithmic change is not defined. Thus, trade policy interventions are treated as specific (per unit) policies, and the differential form differs from the other equations:

(152) $\text{dln}(\mathbf{X_t}) = \boldsymbol{\varepsilon_x}*[\mathbf{Pm_t - tx}]^{-1}*(\text{dln}(\mathbf{Pm_t}) - \text{d}\mathbf{tx}) + \text{dln}(\boldsymbol{\lambda_x})$,

(153) $\text{dln}(\mathbf{M_t}) = \boldsymbol{\eta_m}*[\mathbf{Pm_t - tm}]^{-1}*(\text{dln}(\mathbf{Pm_t}) - \text{d}\mathbf{tm}) + \text{dln}(\boldsymbol{\lambda_m})$,

where $\boldsymbol{\varepsilon_x}$ and $\boldsymbol{\eta_m}$ are the matrices of excess demand and excess supply elasticities facing the United States.

Each commodity has a market-clearing condition, as given by equation (65). Totally differentiating that identity in column vectors gives:

(154) $\mathbf{M_t}*\text{dln}(\mathbf{M_t}) = \mathbf{DF_t}*\text{dln}(\mathbf{DF_t}) + \mathbf{DD_t}*\text{dln}(\mathbf{DD_t}) + \mathbf{X_t}*\text{dln}(\mathbf{X_t}) + \mathbf{I_t}*\text{dln}(\mathbf{I_t}) - \mathbf{Q_t}*\text{dln}(\mathbf{Q_t}) - \mathbf{I_{t-1}}*\text{dln}(\mathbf{I_{t-1}})$,

where **DD** is a vector of derived demands for animals and for feed ingredients.

Margin-markup equations (66) and (67) become:

(155) $\text{dln}(PM_{i,t}) = (Pm_{i,t}/PM_{i,t})*\text{dln}(Pm_{i,t}) + (SPDW_{i,t}/PM_{i,t})*\text{dln}(SPDW_{i,t})$,

(156) $\text{dln}(PR_{i,t}) = (PM_{i,t}/PR_{i,t})*\text{dln}(PM_{i,t}) + (SPDR_{i,t}/PR_{i,t})*\text{dln}(SPDR_{i,t})$.

Appendix B—Numerical Model Data and Numerical Form

This appendix describes the inputs to the numerical model. At a broad level, two sets of information, data and parameters, are required, but those broad categories disguise much detail.

Data

The majority of data required for the model consists of quarterly supply, use, and price data for the years 2001-04. These values set the baseline to which the percent changes are applied. With some exceptions, the data are reported in the Livestock Marketing Information Center (LMIC) database. Data not in the LMIC database consist of data for crops and some trade data. Quarterly supply, use, and price data for coarse grains, wheat, and rice come from situation reports prepared by the Economic Research Service of the U.S. Department of Agriculture (USDA/ERS). Quarterly supply and use tables for the soybean complex prepared by USDA/ERS cover the later years, but not 2001. The missing values for 2001 are generated using the newer data and assumptions about use patterns.

Forage and pasture data are difficult. Forage prices are reported by USDA/ERS in the *Livestock, Dairy, and Poultry Situation and Outlook* report. Total quarterly use is generated by feed balance spreadsheets, where data on animal numbers are combined with standard feeding practices to produce estimates of quarterly feeding of forage and pasture. Production numbers are limited. Production of hay, corn silage, and sorghum silage are reported by the National Agricultural Statistics Service, U.S. Department of Agriculture (USDA/NASS, *Crop Production*). No recent data exist for grazed pasture. While there is some early forage harvest, there is no way to know how much of the forage is harvested in the second quarter of the year. The assumption in this model is that forage harvest occurs in the third quarter. Given the quarterly use and third-quarter production, the residual is treated as grazed pasture. This residual is allocated equally to quarters 2 and 3, with no forage and pasture production in quarters 1 and 4. With this information, quarterly supply and use is calculated so that no quarter from the first quarter of 2001 to the fourth quarter of 2004 shows a negative carryover.

While LMIC and USDA/ERS report aggregate trade data for animals, the model requires decomposing those data into animals for slaughter and those to be fed. The data are obtained originally from U.S. Customs via the Foreign Agricultural Service, U.S. Department of Agriculture (USDA/FAS).

Policy information affecting crop variables comes from various sources. The policy data for 2001 and 2002 are reported by Nelson and Schertz (1996) in *Provisions of the Federal Agriculture Improvement and Reform Act of 1996*. Policy data for the 2002 Farm Act are taken from the Outlook reports prepared by USDA/ERS: *Rice, Wheat, Feed, Grains, and Oilseeds and Products*.

Parameters

Four sets of parameters drive the model: the livestock feed-balance calculator, the most complicated of the four; the revenue shares for all industries; elasticities used in model solution; and disease-related parameters used to manipulate disease scenarios. The numerical model is constructed so that the user can alter the parameter values, because for many values there is no consensus in the literature. The first three sets of parameters discussed here are the default values based on estimates in the literature, as well as on the authors' judgments in some cases. The animal disease parameters are discussed in the empirical section.

Livestock-Feed Balance

The livestock-feed balance calculators are critical because they relate the stocks and flows of animals for each quarter to the feed supplies available, forming the critical vertical linkage between the animal agriculture component and the crop component. Feed-use calculations, outlined in this section, incorporate information on foreign-born pigs, mortality rates, feed efficiency, and other factors.

Market Swine

The first step in determining swine feed consumption was formulating a typical swine diet for a market pig. Weight ranges (10-59 pounds, 60-119 pounds, 120-179 pounds, and 180-plus pounds) are consistent with those in the quarterly *Hogs and Pigs* (USDA/NASS), in which inventory numbers are reported for each weight category. However, in development of the model, the inventory numbers were not used to track pig flows. Instead, we used monthly farrowings, but the intervals were used to formulate diet specifications.

The next step was to determine weight gain and feed consumption in the weight categories. This information and all diet formulations are from the *Pork Industry Handbook* (PIH) (Purdue University, ongoing publication) and *The Kansas Swine Nutrition Guide* (Tokach et al.). From the beginning and ending weights in each phase, the model calculated the total weight gain and tracked how much feed is consumed for this weight gain. For example, a pig must consume a total of 92 lbs of feed in a quarter to go to 60 lbs. The calculations assumed an average feed efficiency of 3 pounds of feed consumed, on an as-fed basis, per pound of gain from 50 lbs to 250 lbs, and were scaled to account for the fact that lighter pigs have better feed-to-weight-gain efficiency than heavier pigs.

Average daily gain was used to calculate how many days each pig spends in each stage. Using these calculations, and assuming each pig starts consuming feed at a weight of 10 lbs, the model found that the total number of days for a pig to go from farrowing to market is 180 days, or two quarters. We combined this information with the percentages of feed ingredients—feed grains, wheat, soybean meal, and premixes/other—in the diet for each phase of production to calculate the daily and total feedstuffs consumed. Mortality rates in the nursery and grower/finisher portions of the production process were used to calculate deaths at each stage of production, since the only statistical input is the pig crop.

Monthly consumption patterns are produced by flow tracking of the monthly pig crop published in *Hogs and Pigs* (USDA/NASS). The intention is to take the monthly pig crop, track that crop for each month, and pinpoint how much feed the pigs are consuming in each month in order to calculate quarterly use.

This calculation starts with the number of days that pigs spend in each stage (e.g., 10-59 pounds, 60-119, etc.). Pigs take approximately 37 days to reach the first weight benchmark. We assumed that each month consists of 30.5 days; therefore, in their first month, the pigs spend all 30.5 days in this stage. Total monthly feed consumption is determined by multiplying 30.5 times the average daily feed consumption for the first stage of production. Continuing to the second month, since there are still 6.5 days left in stage 1, the pigs born in that first month spend 6.5 days in stage 1 and the remaining 24 days in stage 2. The amount of feed they consume is found by multiplying the number of days in each stage by the daily consumption for that stage. This pattern is carried out for the remainder of the months to give a schedule of total consumption for each pig crop.

To calculate total monthly feedstuff consumption by domestic pigs, multiply each monthly pig crop times its monthly consumption of each feedstuff. For example, for consumption in January, the total number of pigs born in December would be multiplied times feed grain consumption for the pigs' first month of production. Also added to January would be pigs born in November times their total consumption in the second month, and so on, back to pigs born in June times consumption in their sixth month of growth. Additionally, pig numbers are adjusted for death losses by multiplying the total number of pigs in their second month and higher by 97 percent (for nursery mortality rate), and pigs in their fourth month and higher times an additional 98 percent (or a compounded 95.06 percent) for mortality in the grow-finish section.

Consumption by foreign-born pigs must also be recognized. The U.S. International Trade Commission (USITC) changed its reporting procedure for import pigs in 2003. For years after 2003, the USITC breaks imports down into more subcategories; however, all can be aggregated into categories of less than 50 kilograms (kg), more than 50 kg not for immediate slaughter, and more than 50 kg for immediate slaughter.

Pigs imported at less than 50 kg are assumed to have entered the United States at the beginning of their second month of life, and those imported at weights greater than 50 kg are assumed to have arrived at the beginning of their fifth month of life.

Breeding Swine

Feed consumption for sows begins with an estimate of 1.9 litters/sow/year (*Pork Industry Handbook*). Additionally, an assumed average weaning age of 25 days is based on an average of several suggested weaning ages in the Pork Industry Handbook. Consequently, on average each sow is in lactation for 47.5 days and is in gestation 317.5 days (365-47.5). Average daily consumption listed for sows in lactation and gestation is multiplied by the total number of days in each stage to give the annual consumption for a sow. This is multiplied by the percentage of the total ration each feed represents to get the number of pounds of each feed consumed per sow per year. Annual quantities are allocated to quarterly consumption by dividing by 4, with no seasonal adjustments.

To get total sow consumption, multiply the calculated consumption patterns times quarterly-average sow inventories. Beginning and ending sow inventories are averaged to represent an average inventory. For example, the numbers from December 1 and March 1 give the average sow inventory for the winter quarter. The dates for hog inventory numbers differ from standard quarters and from inventory data for other species. Since the data show little fluctuation, such differences in timing are ignored. Multiply the average inventory times the quarterly consumption of feed grains per sow to get the total quarterly consumption of feed grains for breeding sows. This procedure was used to calculate quarterly consumption for wheat, coarse grains, soybean meal, and premixes/other.

Market Beef

Slaughter data for cattle are monthly Federally Inspected (FI) slaughter of steers and heifers. Inventory numbers are from the semiannual report, *Cattle* (USDA/NASS), and all trade numbers are from the USITC website.

The time from when a beef market animal is born until slaughter is assumed to be five quarters, and diets are developed over this time span. Calves are assumed to be weaned at approximately 6 months and not fed any creep rations (supplements to mother's milk to encourage growth) prior to weaning. Therefore, after weaning, calves spend 3 months in background lots, 3 months in grower lots, and 3 months in a full feedlot (finishing). As with hogs, weights at the beginning and ending of each stage give total weight gain and average daily gain. All months are assumed to be 30.5 days. Average dry matter intake (DMI) is calculated by taking 2.5 percent times the average body weight in the stage. This formula and all feeding rations are based on information from Kellems and Church (2002), Jurgens (1978), and Field and Taylor (2003).

The previous calculations yield average daily consumption of *dry matter* by calves in each stage. The next calculations break this down between feed grains, forages, wheat, soybean meal, and other. Ultimately, the consumption of dry matter by cattle is converted into an as-fed basis. Therefore, a rough estimate of the percentage of dry matter for each component is required. The most challenging part is to decide what percent to use for forages because of the combination of dried forages and forages fed in pastures. Next, the percentage in each quarter of feed grains, forages, wheat, and soybean meal fed on an as-fed basis is used to convert the total dry-matter daily consumption into the average daily consumption of each component, which then aggregates to the total consumption of each component in that stage of production.

Combining monthly slaughter into quarterly estimates, and then subtracting imports for immediate slaughter, gives the number of slaughtered animals raised in the United States. Aggregate slaughter and the calculated consumption at each stage determine total consumption. For example, to get total consumption for quarter 1 of 2003, take those cattle slaughtered in quarter 1 of 2003 times consumption in the fifth stage, plus those that are slaughtered in quarter 2 of 2003 times consumption in the fourth stage, plus those slaughtered in quarter 3 of 2003 times consumption in the third stage. This is broken down into grains, forages, wheat, and soybean meal. One drawback with this method is that total feed consumption in the current period cannot be calculated until there are slaughter data from 6 to 9 months ahead, needed to capture the flow of cattle and their consumption at each stage of growth.

Beef Cows

The diet of a cow is modeled based on the dietary requirements of her annual production cycle. She spends one quarter each in trimester I, trimester II, trimester III, and postpartum. The dry matter recommendations have correspondingly been included. Then, given the percentage of each component that makes up the whole diet in that stage, the total feed grain, forage, wheat, and soybean meal consumption can be calculated for the stage.

The cow inventory data are for the first and third quarters; USDA does not record data for the second and fourth quarters.[1] The best method is simply to average the two points to get a midpoint inventory number. Another aspect is the seasonality of calving. NASS reports indicate that approximately 70 percent of cows calve in the first half of the year. Therefore, it is assumed that 35 percent calved from January to March, 35 percent from April to June, 15 percent from July to September, and 15 percent from October to December.[2]

Finally, multiplying the total number of cows times the percentage in each stage times the total consumption in that stage gives the quarterly consumption by cows. This calculation rolls, so for each quarter of the year the number of cows in each stage should be appropriately modeled to depict seasonality in calving.

[1]An attempt was made to estimate second- and fourth-quarter inventory levels by subtracting quarterly cow-slaughter numbers and then adding in the change in the number of heifers, but the estimates appeared to be highly inaccurate.

[2]Other data show much more calving in the first quarter and much less in the third quarter, with 82 percent of calves born in the first half of the year. Since the NASS data are used in our calculations, calving percentages consistent with that data are used.

Dairy Cows

The method for tracking the consumption by dairy cows is the same as for beef cows. The difference is in dry matter intake (DMI) at each stage of production. All consumption patterns for dairy cows were modeled after the National Research Council (NRC) nutrient recommendations for dairy cows and the interactive CD accompanying these recommendations. These sources indicate that cows go through a stage of peak milk production, followed by a stage where milk production decreases somewhat but total intake is maximized, a cow-weight recovery stage, and then a dry period.

Beef and Dairy Heifers

Replacement heifers include animals not already counted in the slaughter data. The approaches to determine quarterly feed use for beef and dairy heifers are identical. The heifer diets, and percentage of each component within the diet, are modeled in the same fashion as the cow diets. The data are for inventories observed on January 1 and July 1 of each year. While most beef cows are in one of four stages of a cycle, replacement heifers range in age from 6 months (just weaned) to 24 months (just prior to first calf, and not yet included in the cow inventory). The approach is to broadly model feed patterns for heifers as they pass through their stages of growth.

Bulls

The typical bull diet assumes that in the summer bulls are fed no grain and simply graze pasture. Bull dry matter intake (DMI) is obtained from estimates in Kellems and Church (2002). For each quarter, multiply the total number of bulls times the consumption per bull during that stage.

Market Sheep

Market sheep are handled similarly to market beef. Average daily dry matter intake is estimated at 4 percent of body weight (as opposed to 2.5 percent for market cattle). Data are available from the USDA/NASS Livestock Slaughter report. As with beef, to get consumption for one quarter, for example January through March, the slaughter from that quarter is multiplied times the consumption in the last quarter of life, plus the slaughter of the next quarter is multiplied times the slaughter of the second-to-last quarter of life, and so on.

Slaughter lambs are assumed to live 4 quarters. This approach assumes that lambs are fed a very low percentage of grain for the first 6 months, and then fed more intensively over the last 6 months. The sheep feeding does not account for any exports/imports.

Ewes

The calculations for ewes are the same as for cows. Inventory numbers are available only for January 1 and July 1, so the inventories in March and October are simple averages of the preceding and succeeding semiannual numbers. The ewe model assumes that 90 percent of the ewes lamb between January and July. This estimate, which is available on the USDA/NASS July Sheep report, has been around 90 percent over the last several years. It is assumed that 45 percent of ewes lambed in the first 3 months and 45 percent in the second 3 months. Seasonality is captured by multiplying the total number of ewes times the approximate percentage in that stage times the consumption for that respective stage. Ewe diets were obtained from Kellems and Church (2002) and Jurgens (1978).

Layers

Calculation of layer feed consumption is direct. Average monthly layer numbers are from Chickens and Eggs (USDA/NASS). The estimated average daily layer consumption was about 100 grams (Leeson and Summers, 1997 and 2001). To get feed grain consumption for 1 month, multiply the total number of layers times the average daily consumption, times the percentage of that consumption that is feed grains, times 30.5 (the number of days in each month). This is done for each feed component and each month and aggregated on a quarterly basis.

Poultry

Feed consumption by market poultry is based on the total pounds of slaughter. A key parameter is the estimated feed conversion factor, 1.5 pounds of feed consumed per pound of gain, from Leeson and Summers (1997 and 2001). The total slaughter weight for each month is multiplied by the conversion factor to obtain the total required feed intake. To get consumption, multiply the total feed intake by the percentage breakdown of each feed component.

Revenue and Factor Shares

Revenue shares appear in the logarithmic differential equation form of the zero-profit conditions (tables 1- 6). Factor shares appear in the logarithmic differential equation form of the land-market clearing.

Appendix table 1
Unit revenue shares for cattle, broilers, and beef used in model[1]

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Cattle[2]				
Exogenous inputs	0.141918	0.141918	0.141918	0.141918
Land	0	0	0	0
Intermediate inputs	0	0	0	0
Feed	0.629065	0.629065	0.629065	0.629065
Coarse grain	0.127212	0.033934	0.035078	0.245662
Wheat	0.006702	0.006099	0.005577	0.010969
Meal	0.008911	0.008773	0.008789	0.017774
Forage	0.48624	0.580259	0.579621	0.354661
Residual cost of capital and management	0.229017	0.229017	0.229017	0.229017
Broilers[3]	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Exogenous inputs	0.219075	0.219075	0.219075	0.219075
Land	0	0	0	0
Intermediate inputs	0	0	0	0
Feed	0.44363	0.44363	0.44363	0.44363
Coarse grain	0.23103	0.22425	0.225201	0.232601
Wheat	0.005314	0.005482	0.004648	0.005252
Meal	0.207286	0.213898	0.213782	0.205777
Forage	0	0	0	0
Residual cost of capital and management	0.337295	0.337295	0.337295	0.337295
Beef[4]	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Exogenous inputs	0.1326	0.1326	0.1326	0.1326
Land	0	0	0	0
Intermediate inputs	0.8371	0.8371	0.8371	0.8371
Feed	0	0	0	0
Coarse grain	0	0	0	0
Wheat	0	0	0	0
Meal	0	0	0	0
Forage	0	0	0	0
Residual cost of capital and management	0.0303	0.0303	0.0303	0.0303

[1]Unit revenue shares are the proportion of unit revenue (price) represented by the cost of each factor of production.

[2]USDA/ERS, Commodity Costs and Returns
http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm

[3]USDA/ERS, 1996. [4]MacDonald et al., 1999.

Appendix table 2

Unit revenue shares for swine, eggs, and pork used in model[1]

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Swine[2]				
Exogenous inputs	0.138985	0.138985	0.138985	0.138985
Land	0	0	0	0
Intermediate inputs	0	0	0	0
Feed	0.625333	0.625333	0.625333	0.625333
Coarse grain	0.397464	0.386924	0.367032	0.377689
Wheat	0.00675	0.006935	0.005635	0.006323
Meal	0.221119	0.231474	0.252666	0.241322
Forage	0	0	0	0
Residual cost of capital and management	0.235682	0.235682	0.235682	0.235682
Eggs[3]				
Exogenous inputs	0.3	0.3	0.3	0.3
Land	0	0	0	0
Intermediate inputs	0	0	0	0
Feed	0.229099	0.229099	0.229099	0.229099
Coarse grain	0.119308	0.115807	0.116298	0.12012
Wheat	0.002744	0.002831	0.0024	0.002712
Meal	0.107046	0.110461	0.110401	0.106267
Forage	0	0	0	0
Residual cost of capital and management	0.470901	0.470901	0.470901	0.470901
Pork[4]				
Exogenous inputs	0.19	0.19	0.19	0.19
Land	0	0	0	0
Intermediate inputs	0.7426	0.7426	0.7426	0.7426
Feed	0	0	0	0
Coarse grain	0	0	0	0
Wheat	0	0	0	0
Meal	0	0	0	0
Forage	0	0	0	0
Residual cost of capital and management	0.0674	0.0674	0.0674	0.0674

[1]Unit revenue shares are the proportion of unit revenue (price) represented by the cost of each factor of production.

[2]USDA/ERS, Commodity Costs and Returns http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm

[3]Calculated from feed balance (assumed). [4]MacDonald and Ollinger, 2000.

Cost-of-production data for corn, wheat, soybeans, rice, hogs, cattle, and milk are obtained from *Commodity Costs and Returns* (USDA/ERS). These data are divided by production revenue to find the revenue shares. Crop revenue includes U.S. Government payments, since they are necessary for land, capital, and management to show positive returns. In general, crops show fairly even allocations among exogenous inputs, land, and the residual cost of capital and management. For live animals, the major revenue share is allocated to feed costs, followed by the residual return to capital and management. Milk is an exception that reflects the way the data are reported. For milk, the animal value is implicit, as the milk costs include feed and veterinary costs. Thus, the large residual to capital and management includes the capital value of the dairy cow.

The remaining revenue shares come from a variety of sources. Forage and pasture revenue shares are from Barnett (2005). Those for poultry meat are

Appendix table 3

Unit revenue shares for milk, lambs and sheep, and poultry used in model[1]

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Milk[2]				
Exogenous inputs	0.192257	0.192257	0.192257	0.192257
Land	0	0	0	0
Intermediate inputs	0	0	0	0
Feed	0.492441	0.492441	0.492441	0.492441
Coarse grain	0.05359	0.015468	0.013019	0.095574
Wheat	0.004559	0.002946	0.002199	0.004154
Meal	0.035768	0.018123	0.024709	0.047621
Forage	0.398525	0.455904	0.452513	0.345093
Residual cost of capital and management	0.315302	0.315302	0.315302	0.315302
Lambs and Sheep[3]				
Exogenous inputs	0.1875	0.1875	0.1875	0.1875
Land	0	0	0	0
Intermediate inputs	0	0	0	0
Feed	0.375	0.375	0.375	0.375
Coarse grain	0.031361	0.028828	0.023288	0.020391
Wheat	0	0	0	0
Meal	0.004003	0.004759	0.003129	0.004839
Forage	0.339637	0.341413	0.348583	0.388552
Residual cost of capital and management	0.4375	0.4375	0.4375	0.4375
Poultry[4]				
Exogenous inputs	0.282	0.282	0.282	0.282
Land	0	0	0	0
Intermediate inputs	0.691	0.691	0.691	0.691
Feed	0	0	0	0
Coarse grain	0	0	0	0
Wheat	0	0	0	0
Meal	0	0	0	0
Forage	0	0	0	0
Residual cost of capital and management	0.027	0.027	0.027	0.027

[1]Unit revenue shares are the proportion of unit revenue (price) represented by the cost of each factor of production.

[2]USDA/ERS, Commodity Costs and Returns http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm

[3]Umberger and McKinnon, 1996. [4]Ollinger, MacDonald, Madison, 2005.

broiler shares obtained from USDA/ERS, AER-747 (1996). The shares for lambs and sheep are from Umberger and McKinnon (1996). Beef shares come from MacDonald, Ollinger, Nelson, and Handy (1999), and pork from MacDonald and Ollinger (2000). Revenue shares for live poultry are from Ollinger, MacDonald, and Madison (2005). In general, meat industries show low residual returns to capital and management because the bulk of revenue is allocated to animal costs. The exceptions are poultry meat and eggs, treated as vertically integrated industries, with firms capturing the difference between meat and egg sales and feed costs. Thus, for poultry and eggs, the value of the animal is implicit, and the firms capture a large residual return to capital and management.

The revenue shares for the individual feed ingredients are calculated from the livestock-feed balances that determine feed use for the individual feeds based on animal numbers. That allows the per animal feed use by feed by animal type to be calculated. Using prices for feeds recorded in the *Livestock, Dairy and Poultry Outlook* report (UASA/ERS), revenue share can be calculated.

The land factor shares are from data taken from USDA/NASS *Crop Production* reports. The USDA/NASS reports indicated the area harvested for the grain, oilseed, and forage crops. The area of pasture has to be determined. The residual forage and pasture determined by the livestock-feed balance calculator is used to determine "production" of pasture for the model solution. This residual is converted to area using the harvested hay yield, and that area is combined with the recorded areas for harvested hay, corn silage, and sorghum silage to give total area for forage and pasture. The areas for the crops included in the model are summed to find the total area, and the factor shares are calculated.

Elasticities

Elasticities are critical parameters that come from a variety of sources. The elasticities can be grouped into several sets. The own- and cross-price elasticities of retail demand are obtained from several studies, and most are based on estimates from econometric models (table 7). Cross-price elasticities are nonnegative, implying that the commodities involved are substitutes and are small, which affects how the model reacts to disease outbreaks that alter prices. There are some spillover effects in meats, but not many elsewhere. The elasticities for beef, pork, and poultry meat are from Holt (2002), who estimated inverse demands for those products. Price flexibilities for meats are converted to elasticities using matrix inversion. In contrast to the more familiar inelastic annual estimates, these values are elastic and indicate the willingness of consumers to alter purchases in response to shortrun price changes. The elasticity of demand for lamb meat is an annual estimate used by Paarlberg and Lee (1998) to examine impacts of a tariff-rate quota for lamb meat, converted in our model to a quarterly figure based on the Holt estimates. The elasticity of demand for milk comes from Gould, Cox, and Perali (1991). The elasticities of demand for wheat and rice are from Gao, Wailes, and Cramer (1995). The elasticity of demand for soybean oil is from Yen and Chern (1992). The elasticity of demand for coarse grains for food and industrial use is based on a policy simulator model by Holland and Meekhoff (1979). The elasticity of demand for eggs comes from Huang (1996).

Substitution elasticities describe derived demand behaviors and affect supplies of the output commodities in the equation from which they are derived (tables 8, 9, and 10). Substitution elasticities for the meats are estimated by MacDonald and Ollinger (2000). Model solutions evaluated by individuals with experience in meatpacking were viewed as having excessive meat-yield changes as capital substituted for animals. Thus, the values used are lowered to reduce meat-yield changes. The substitution elasticities for animal feeds are generated with a technique used by McKinzie, Paarlberg, and Huerta (1986) that requires developing least-cost feed rations by animal species. Then, varying the prices of each ingredient, a set of pseudo-data is created through which share equations can be estimated from which, in return, the substitution elasticities relative to coarse grains can be extracted. With some exceptions, the estimated elasticities ranged from 0.7 to 1.2. The substitution elasticities for wheat use in cattle and swine feeds relative to coarse grains are 0.34 and 2.52, respectively. The substitution elasticity of forage and pasture relative to coarse grains in cattle feeding is estimated at 2.35. Estimates for the remaining substitution elasticities were not found, so values are used—given the differential supply equations, equations (139)-(143)—that are consistent with commonly accepted supply elasticity values. These are low and indicate little input substitution.

There are a number of elasticities tied to animal agriculture inventories. These are econometrically estimated as part of the study (table 11). There are again a couple of exceptions. Bird numbers are tied directly to poultry meat and egg outputs with elasticities of 1. This means there is no substitution between birds and other inputs in meat and egg production. If poultry output falls 10 percent, bird numbers fall 10 percent. The same relationship is imposed on milk production and dairy cow numbers.

International trade elasticities were difficult to obtain in many cases since, despite decades of research, there is little consensus about the magnitudes. Further, for the model to behave correctly for livestock disease issues, intra-sector trade must be modeled. This is done by inserting both excess demand and excess supply functions. The elasticities of excess demands for beef, pork, and poultry meat are from estimates for Japanese purchases of U.S. meats by Yang and Koo (1994) (table 12). The estimates for beef are similar to the values reported by Zhao, Wahl, and Marsh (2006). The excess demand elasticities for coarse grains, wheat, and soybeans and products are from policy simulators. The other trade elasticities are assumed. These are set at either 0 or 1, with some exceptions. Those for lamb meat, eggs, and rice are set in the elastic range. The elastic excess supply to the United States reflects that little lamb meat is consumed in the United States compared with other meats, global lamb meat trade is small, and lamb meat is more important to other countries. For rice, the excess demand is elastic because very little rice moves in world markets, even though the United States is a major exporter. Egg exports are small relative to U.S. and rest-of-world production.

Finding ending stocks elasticities proved difficult, since these values are rarely reported in the current literature. Older studies did include ending stock estimates, exclusively for crops. An elasticity for wheat can be found in Gallagher et al. (1981). An ending stocks elasticity for rice appears in Cramer et al. (1990). Experiments with model solutions produced a set of elasticities that gave reasonable behavioral responses (table 13). The ending stocks elasticity for forage and pasture is estimated using the quarterly data calculated from the livestock-feed balance workbook.

The remaining ending stocks are treated as residuals in the model solution, so that the elasticities are implicit. This is done because the stocks for these commodities are generally small relative to use, and some commodities like soybean meal are difficult to store. Thus, ending stocks for such commodities are treated mostly as transaction or pipeline stocks. The model solutions suggest that these implicit percentage changes are small.

Appendix table 4

Unit revenue shares for lamb and sheep meat and coarse grains used in model[1]

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Lamb and sheep meat[2]				
Exogenous inputs	0.2	0.2	0.2	0.2
Land	0	0	0	0
Intermediate inputs	0.75	0.75	0.75	0.75
Feed	0	0	0	0
Coarse grain	0	0	0	0
Wheat	0	0	0	0
Meal	0	0	0	0
Forage	0	0	0	0
Residual cost of capital and management	0.05	0.05	0.05	0.05
Coarse grains[2]				
Exogenous inputs	0.42792	0.42792	0.42792	0.42792
Land	0.254407	0.254407	0.254407	0.254407
Intermediate inputs	0	0	0	0
Feed	0	0	0	0
Coarse grain	0	0	0	0
Wheat	0	0	0	0
Meal	0	0	0	0
Forage	0	0	0	0
Residual cost of capital and management	0.317673	0.317673	0.317673	0.317673

[1]Unit revenue shares are the proportion of unit revenue (price) represented by the cost of each factor of production.

[2]USDA/ERS, Commodity Costs and Returns http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm and *Feed Outlook*.

Appendix table 5

Unit revenue shares for forage and wheat used in model[1]

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Forage[2]				
Exogenous inputs	0.5	0.5	0.5	0.5
Land	0.16	0.16	0.16	0.16
Intermediate inputs	0	0	0	0
Feed	0	0	0	0
Coarse grain	0	0	0	0
Wheat	0	0	0	0
Meal	0	0	0	0
Forage	0	0	0	0
Residual cost of capital and management	0.34	0.34	0.34	0.34
Wheat[3]				
Exogenous inputs	0.493707	0.493707	0.493707	0.493707
Land	0.316117	0.316117	0.316117	0.316117
Intermediate inputs	0	0	0	0
Feed	0	0	0	0
Coarse grain	0	0	0	0
Wheat	0	0	0	0
Meal	0	0	0	0
Forage	0	0	0	0
Residual cost of capital and management	0.190176	0.190176	0.190176	0.190176

[1]Unit revenue shares are the proportion of unit revenue (price) represented by the cost of each factor of production. [2] Barnett, undated.

[3]USDA/ERS, Commodity Costs and Returns http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm and *Wheat Outlook*.

Appendix table 6

Unit revenue shares for rice and soybeans used in model[1]

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Rice[2]				
Exogenous inputs	0.479147	0.479147	0.479147	0.479147
Land	0.172603	0.172603	0.172603	0.172603
Intermediate inputs	0	0	0	0
Feed	0	0	0	0
Coarse grain	0	0	0	0
Wheat	0	0	0	0
Meal	0	0	0	0
Forage	0	0	0	0
Residual cost of capital and management	0.34825	0.34825	0.34825	0.34825
Soybeans[3]				
Exogenous inputs	0.321523	0.321523	0.321523	0.321523
Land	0.331835	0.331835	0.331835	0.331835
Intermediate inputs	0	0	0	0
Feed	0	0	0	0
Coarse grain	0	0	0	0
Wheat	0	0	0	0
Meal	0	0	0	0
Forage	0	0	0	0
Residual cost of capital and management	0.346642	0.346642	0.346642	0.346642

[1]Unit revenue shares are the proportion of unit revenue (price) represented by the cost of each factor of production.

[2]USDA/ERS, Commodity Costs and Returns
http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm and *Rice Outlook*

[3]USDA/ERS *Costs of Production* and *Feed Outlook*.

Appendix table 7

Price elasticities for final goods

	Beef	Pork	Poultry	Lamb	Dairy	Eggs	Wheat	Rice	Coarse grains	Soy oil
Beef	-1.521	0.077	0.206	0.789	0	0	0	0	0	0
Pork	0.077	-1.45	0.32	0	0	0	0	0	0	0
Poultry	0.206	0.32	-2.677	0.263	0	0	0	0	0	0
Lamb	0.789	0	0.263	-1.052	0	0	0	0	0	0
Milk	0	0	0	0	-0.397	0	0	0	0	0
Eggs	0	0	0	0	0	-0.1103	0	0	0	0
Wheat	0	0	0	0	0	0	-0.309	0.036	0	0
Rice	0	0	0	0	0	0	0.229	-0.328	0	0
Coarse grain	0	0	0	0	0	0	0	0	-0.4	0
Soy oil	0	0	0	0	0	0	0	0	0	-0.314

Sources: Various, as described in text.

Appendix table 8

Elasticities of substitution in meat production relative to capital

	Exogenous inputs	Animal
Beef	0.338944	0.2
Pork	0.428395	0.2
Poultry meat	0.435933	0.2
Lamb meat	0.443000	0.2

Source: MacDonald and Ollinger, 2000.

Appendix table 9

Elasticities of substitution in livestock relative to coarse grains

	Exogenous inputs	Wheat	Meal	Forage pasture
Beef cattle	0.3	0.341903	0.933330	2.3474
Swine	0.3	2.528800	0.971301	NA
Broilers	0.3	0.702133	0.893466	NA
Dairy cattle	0.3	0.706631	0.915752	1.1248
Layers	0.3	0.702000	1.070307	NA
Lambs and sheep	0.3	0.510600	-0.01110	0.494

NA= Not Allowed.

Source: Estimated using technique in McKinzie, Paarlberg, and Huerta, 1986.

Appendix table 10

Elasticities of substitution for crops relative to capital

	Exogenous inputs	Land
Wheat	0.3	0.3
Coarse grains	0.3	0.3
Soybeans	0.3	0.3
Forage and pasture	0.3	0.3
Rice	0.3	0.3

Source: Based on differential supply equations, equations (139)-(143), and consistent with commonly accepted supply elasticity values..

Appendix table 11

Elasticities used in model solution to capture animal dynamics

Dependent variable	Value	Independent variable
Layer numbers[1]	1	Egg output, current period
Bird numbers[1]	1	Poultry meat output, current period
Slaughter cattle, post-birth, calves	1	Number of cows, current period
Beef cows	0.014551	Replacement beef heifers, t-8
Beef cows	0.028313	Expected return cow sold t+9 relative to current sale
Pig crop	0.526875	Breeding hog inventory, previous period
Forage inventory	0.13591	Price next relative to current value
Replacement beef, heifers	0.106481	Expected return animal sold t+16 relative to t+5
Pig crop	0.001921	Expected price hogs t+2 relative to price t-1
Hog breeding Inventory	0.025028	Current price of hogs
Hog breeding inventory	0.855952	Last quarter's breeding inventory for hogs
Milk cow numbers[1]	1	Milk output
Replacement heifers, dairy	0.083785	Expected price milk t+8 relative to price of cattle t+5
Ewes	0.042211	Expected return to ewes t+4 -t+8 relative to current value
Ewes	0.85	Ewe inventories t-1
Replacement ewes	0.03408	Expected return t+4-t+12 relative to current period
Replacement ewes	0.85	Replacements t-1
Lamb crop	0.900894	Ewes
Beef cow inventory	0.85	Lagged inventory
Dairy cow inventory	0.85	Lagged inventory
Broilers	0.05	Lagged output
Layers	0.15	Lagged output

[1]Exceptions assumed equal to 1.0.

Source: Econometrically estimated by authors, except as noted.

Appendix table 12

Elasticities for international trade used in model

Commodity	Exogenous demand	Excess supply
Wheat	0.3	0.3
Beef	-1.010	1.00
Pork	-0.890	1.00
Poultry meat	-0.448	0.00
Lamb meat	0.000	5.00
Cattle	-1.000	1.00
Swine	-1.000	1.00
Birds	0.000	0.00
Milk/dairy	0.000	5.00
Eggs	-5.000	0.00
Lambs	-1.000	1.00
Wheat	-0.700	0.00
Coarse grains	-1.500	0.00
Soybeans	-1.000	0.00
Forage and pasture	0.000	0.00
Rice	-5.000	0.00
Soybean meal	-1.500	0.00
Soybean oil	-2.000	0.00

Source: Estimates compiled from a number of sources, excess supply and demand functions, and authors' best judgment.

Appendix table 13

Elasticities for ending stocks

Commodity	Elasticity of expected price to current prices
Wheat	0.8
Coarse grains	0.8
Soybeans	0.8
Rice	0.8
Soybean oil	0.5
Milk	0.8
Forage and pasture	0.13591

Source: Adapted from various published sources.

Appendix table 14

Number of animals destroyed in a hypothetical FMD outbreak

Scenario	Dairy	Sheep	Hogs		Cattle	
			Market	Breeding	Market	Breeding
Slaughter of direct-contact animals:						
Low	0	0	4,559.00	0	0	0
Mean	121.72	3.02	21,501.32	777.22	50.00	4.54
High	981.00	108.00	70,290.00	6,047.00	123.00	33.00
Slaughter of direct- and indirect-contact animals:						
Low	0	0	4,559	0	0	0
Mean	117.01	16.66	20,143.48	630.29	72.49	17.75
High	2,263.00	994.00	58,790.00	6,117.00	1,472.00	233.00
Ring slaughter of all animals within 1 km:						
Low	0	0	5,387.00	0	83.00	0
Mean	75.84	0	16,045.10	471.20	98.32	4.88
High	588.00	0	43,796.00	5,999.00	291.00	38.00

Source: Model estimation results.

Appendix table 15

Changes in aggregate net returns to capital and management

Sector	Standard outbreak	High outbreak
	Million dollars	
Beef processing	7	-3
Beef cattle	-1,958	-3,072
Pork processing	-93	-279
Swine	-1,559	-2,079
Lamb and sheep meat	18	31
Lamb and sheep	-10	-14
Poultry meat	-77	-118
Eggs	2	4
Milk/dairy	781	1,272
Soybean crushing	4	3
Crops	112	193
Total	-2,773	-4,062

Source: Model estimation results.