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 simula-

tion 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.