A Spatial Model of Animal Disease Control in Livestock: Empirical Analysis of Foot and Mouth Disease in the Southern Cone

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Abstract: This paper presents a multi-market model of animal disease control that extends the current literature by accounting for spatial and inter-temporal relations in both epidemiological and economic variables. The model is applied to Foot and Mouth Disease control in Argentina, Uruguay and Paraguay, but it is broadly generalizable.

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Introduction

Animal disease outbreaks present significant costs to affected countries, especially when the livestock sector is large and substantially integrated into international export markets. For example, the recent discovery of Bovine spongiform encephalopathy (BSE) in cattle in the United States resulted in the nearly immediate closure of almost 90 percent of the U.S. export market. While the loss of access to export markets may be brief in duration, animal diseases can also imply considerable expenditures in disease control efforts, indemnity payments for destroyed animals, lost production, and losses in related industries, including tourism as in the case of foot and mouth disease (FMD) in Great Britain in 2001.

Despite the economic importance of animal disease outbreaks, there has been relatively little work to combine realistic epidemiological models with sophisticated economic analysis. Because animal diseases (and production cycles) have particular evolutions through time and space, analysis should ideally be both spatial and dynamic. The importance of the spatial component is often reinforced both by movements of animals and disease spread vectors that are exogenous to animal movement. Meanwhile, time plays an important part in animal disease control analysis because of the dynamic and even stochastic nature of disease outbreaks and because of the roles of investment in livestock economics. This paper develops a partial-equilibrium, multi-market model of animal disease control that, in contrast to the existing literature, is both dynamic and spatial. The model is intended to support analysis of policies to control foot and mouth disease (FMD) in the Southern Cone.

The dynamic nature of the model differs from past models of FMD control and represents a methodological improvement to previous work on animal disease control.

Previous partial-equilibrium models have either been static, one-period analyses that measured the short-run shocks to supply, productivity, and exports (Schoenbaum and Disney, 2003; Mangen et al., 2002) or have simply discounted the impact of one period over time (Berentsen et al., 1992). Since an FMD outbreak will engender changes in breeding decisions and input allocation in future production, a dynamic approach is needed to capture the economic effects, as well as the dynamics of disease itself. The model results are combined with exogenous costs including vaccination, eradication, veterinary services, and other government expenditures to determine the total costs of an outbreak over the five-year period under two types of control strategies: (1) a vaccination-only strategy and (2) a stamping out policy.

Preliminary results indicate that the net present value of the stamping out policy is higher than that of a vaccination-only policy, due to higher export values and less severe domestic price effects. However, these results are subject to the caveat that the benefits from any disease control effort depend substantially on the strategy of neighboring countries and regions and cross-border effects may mitigate a successful stamping-out policy (Rich and Winter-Nelson, 2004b). These results thus imply a need for a coordinated multinational approach.

An Overview of FMD

Foot-and-mouth disease is a vesicular disease affecting cloven-hoofed animals, such as cattle, pigs, sheep, goats, deer, and buffalo. Animals infected with FMD develop blister-like lesions on the mouth and foot. FMD is generally not fatal in livestock, though mortality in animals less than one year is significantly higher; for swine, for example, mortality rates have been estimated at 80 percent for young animals less than twenty pounds (McCauley, 1979). In addition, pregnant livestock infected with FMD are at significantly greater risk of spontaneous abortion. The main impact of FMD on infected livestock is reduced productivity. Infected animals often lose weight during the course of infection, resulting in greater costs in feed and shelter. Infected dairy cattle generally produce less milk during the infectious period. In most cases, animals recover from FMD without any permanent ill-effects, though this is far from universal (McCauley, 1979).

The economic significance of an FMD outbreak can be greater than these productivity effects might suggest due to the impact of the disease on market access. Partly because the disease spreads rapidly and can be costly to contain, countries that are not FMD-free (as designated by the International Office of Epizooties, or OIE) have reduced market access to countries that are FMD-free, with exports limited to certain types of meat (e.g., processed meat). Sanitary restrictions on trade thus create a segmented market in which fresh meat products from countries that are FMD-free sell at a price premium (between 10-50 percent) over products that do not have this designation (Ekboir et al., 2002).[1] Moreover, certain high-value international markets, such as Japan and Korea, make a further distinction between FMD-free countries in which vaccination is practiced and those that are FMD-free without vaccination. The "zero-risk policy" towards fresh meat imports in these markets allows imports only from FMD-free sources.

Trade restrictions create powerful incentives to eliminate FMD in countries with export potential, but the costs of doing so are substantial. The countries of the Southern Cone (Argentina, Uruguay, Paraguay, and Brazil) have struggled over the past century to eradicate FMD from their cattle herds. After Argentina and Uruguay successfully eradicated the virus in the mid-to-late 1990s and gained access to many new export markets, FMD reappeared in 2000-2001, resulting in significant export losses. Many high-value markets remain inaccessible to exports from much of this region due to its disease status.[2]

FMD control strategies vary by country and context. The policy in the United States in the wake of an outbreak is to slaughter infected herds and herds in direct contact with infected herds, usually defined by a pre-set radius from the infected herds. This policy is often called “stamping out”. Ring vaccination is conducted for herds outside the control zone to create a buffer area to further control the spread of disease. Movement controls are also implemented. In countries where FMD is endemic, vaccination is the primary control strategy, with contact slaughter and additional ring vaccination occurring for a specific outbreak. In Southern Africa, where FMD is largely spread by wildlife, FMD control zones have been established in which the control zone is surrounded by two electrified fences with a 1-km buffer area. This strategy has been relatively successful until recently, when FMD outbreaks breached the FMD control zones in Zimbabwe and South Africa. In the Southern Cone, vaccination was used to eradicate the disease in 1990s, after which time stamping out was employed to treat isolated outbreaks. Because the massive scope of the 2001 outbreaks in Argentina and Uruguay precluded stamping out, mass vaccination of cattle herds was used.[3]

Applications of economics in animal disease models

Standard models of animal disease typically use partial budgeting forms of benefit-cost analysis (BCA) in conjunction with epidemiological models of disease spread (e.g., a state-transition model) to assess the costs and benefits of alternative strategies (Miller, Tsai, and Forster, 1996; Horst, 1998; Nielen et al., 1999; Perry et al., 1999; Disney et al., 2001; Bates, 2002; Randolph et al., 2002). These models are particularly useful at the herd and farm level and have the additional advantage of being transparent and easy-to-use (Rich and Winter-Nelson, 2004a), but they are unable to capture price or welfare effects, linkages between sectors, and adjustment processes that can occur as a result of an outbreak (cf. Berentsen et al., 1992).

In response to the limitations of such types of benefit-cost models, several methodological approaches have been used in recent disease control models; a thorough review of these models can be found in Rich and Winter-Nelson (2004a). Many analysts have used input-output (I-O) models (or social accounting matrices) to derive sectoral multipliers, which measure the impact in the economy of a final demand shock in the livestock sector caused by a disease outbreak. (Garner and Lack, 1995; Caskie et al., 1999; Ekobir, 1999; Mahul and Durand, 2000). Typically, multipliers are computed for labor markets, households, and the livestock and related sectors. An epidemiological model is usually used to calibrate the size of the shock and combined with the multipliers to compute the total impact of various disease strategies. While I-O models are intuitively appealing, they suffer from two main drawbacks that have been generally overlooked in previous analyses. First, input-output models are fundamentally demand-driven models that assume supply is perfectly elastic. However, long production cycles, particularly for cattle, make this assumption problematic such that one could argue that livestock supply is in fact predetermined (Eales and Unnevehr, 1993). Moreover, the nature of most animal diseases represents a supply shock, as well as a demand shock. (BSE is an important exception). As a result, past studies likely overstate the impact of past outbreaks (Sadoulet and de Janvry, 1995). Second, previous studies ignored potentially important countervailing impacts in employment, since a disease outbreak can generate employment and income depending on the mitigation strategy. Rich (2003) uses an empirical model of FMD control in Zimbabwe to illustrate the scale of these two effects.

Aside from I-O models, computable general equilibrium (CGE) models have been used occasionally to model animal disease issues, but only rarely (Perry et al., 2003 is an exception) in concert with epidemiological models. Recent analyses of animal disease in Ireland (O'Toole et al., 2002) and England (Blake et al., 2002) have treated disease-related shocks to the economy as an exogenous shock, rather than calibrated from a state-transition disease spread model, for instance. While CGE models have merit in their ability to model economy-wide phenomenon, an agriculture-based shock such as an animal disease outbreak requires a detailed, agriculture-based SAM to perform an appropriate analysis. Partial equilibrium models have also not been used with great frequency in animal disease analysis. Amosson et al. (1979) used a partial equilibrium model to evaluate the benefits of brucellosis control. Berentsen et al. (1992) used a single-sector partial equilibrium model to derive welfare impacts from alternative disease control strategies of FMD in the Netherlands. Multisectoral models have only been used recently for animal health applications. Mangen et al. (2002) used a vertically-integrated model of the hog industry in the Netherlands in her analysis of Classical Swine Fever in the Netherlands; related input and output markets were not used in her model, however. Schoenbaum and Disney (2003) used the USMP model originally designed by USDA-ERS in the mid-1980s to compute welfare effects of alternative FMD control scenarios for the United States.

In the next section, we illustrate the specification of a partial-equilibrium, multi-market model of animal disease control that is both dynamic and spatial and could be easily calibrated to an epidemiological model of disease spread. The model, (DISease COntrol Spatial Economic Model, DISCOSEM) is applied to FMD in the Southern Cone countries of Argentina, Uruguay, and Paraguay.

Structure of DISCOSEM

DISCOSEM is a dynamic, spatial, multimarket partial-equilibrium model that concentrates on modeling economic phenomenon in the agricultural side of the economy. DISCOSEM is based on spatial equilibrium models developed in the Markets and Structural Studies Division at the International Food Policy Research Institute (Minot and Goletti, 1998) and employs mixed complementary programming (MCP) as a solution technique. This is in contrast to the majority of spatial equilibrium models which use quadratic programming or price endogenous modeling techniques (Takayama and Judge, 1971; McCarl and Spreen, 1980) to derive optimal prices and movement of trade across regions. Quadratic programming models involve the maximization of producer and consumer surplus subject to flows of products across regions. In an MCP model, the equations that specify the model are essentially the first-order, Kuhn-Tucker conditions of the quadratic programming model (Rutherford, 1995). This yields a system of n equations and n unknowns, in which a subset of the unknowns are the corresponding shadow prices (Lagrange multipliers) from the maximization problem. Each inequality constraint is affiliated with a complementary variable (i.e., its shadow price). If the inequality constraint, $f(x) > 0$ is binding, an additional equation $(\lambda > 0)$ must enter the system to ensure that the complementary slackness condition, $\lambda f(x) = 0$ holds. Unlike a quadratic programming model, MCP models have no objective function as they are a square *n* by *n* system. However, the complementary variables must be associated with the relevant equations in GAMS in the model statement to ensure solution.

An advantage of MCP over quadratic programming models is in the flexibility the former approach provides the analyst. In a quadratic programming model, supply and demand curves are necessarily linear in order to preserve the integrability of the objective function. As a consequence, non-linear taxes (e.g., ad valorem tariffs) and non-linear demand systems (e.g., Rotterdam or AIDS) cannot be used in a quadratic programming model. By contrast, an MCP model can utilize well-behaved, non-linear functional forms in both supply and demand equations, thus allowing for the use of complex functional forms and systems.

A total of six economic sectors are modeled: cattle, beef, pork, lamb, corn, and soybeans; cattle inventories are also included.[4] In the beef sector, quality components that differentiate beef cuts are used to better represent the impact of FMD on export markets. This entails separating the beef market into a high-quality component and a low-quality component. High-quality cuts are those that are mainly traded on world markets as chilled or frozen cuts, while low-quality cuts are mainly consumed domestically.

A five-year time horizon is used in the model reflecting the adjustment processes resulting from an outbreak. The model is solved recursively, such that changes to animal inventories, population, and per capita income drive the data generating process for each period (Day and Cigno, 1978). The dynamic nature of the model distinguishes it from past models of animal disease control. Previous partial equilibrium analyses have been static, one-period analyses that have determined the short-run shocks to supply, productivity, and exports that would result from an outbreak (Mangen et al., 2002; Schoenbaum and Disney, 2003). Those analyses that have been dynamic have generally been of either a benefit-cost approach (Randolph et al., 2002) or have simply discounted the impact of a one-period model over time (Berentsen et al., 1992). However, an FMD outbreak will also engender changes in breeding decisions and input allocation in future production, which in turn will have welfare impacts in the economy over time. Thus, a dynamic approach is suggested to capture these changes. Space is incorporated in DISCOSEM through the modeling of trade flows between three regions in Argentina (Patagonia and Cuyo, Pampas, and the North of Argentina), Uruguay, and Paraguay. The interactions between regions, in terms of regional trade, are modeled explicitly in DISCOSEM. The advantage of this is to capture animal movements and regional welfare, as well as to model the differential effects on an outbreak on a regional basis. This is important in the context of the Southern Cone, particularly Argentina, given the specialization of regions in certain types of production (breeding, fattening, slaughter).

Unlike CGE models, non-agricultural sectors are not explicitly modeled nor are capital, employment, or foreign exchange markets. The economic effects generated by this model thus preclude many possible economic linkages. The choice of a partial equilibrium model over other multisectoral models (input-output, CGE) was made for a number of reasons. First, a partial equilibrium model allows for greater flexibility in modeling phenomenon in the agricultural sector than either I-O or CGE methods, particularly in a multi-region, multi-country framework. The Argentina I-O table, for example, is a 73 *X* 73 table with separate sectors for agriculture, livestock, meat production, and dairy production. However, the Argentina I-O model is a national model, thus precluding the straightforward inclusion of regional impacts. Moreover, the level of detail in the Argentina I-O table is greater than that which exists for Uruguay; it is unknown whether an input-output table exists for Paraguay. The lack of coordination among sectors in different I-O tables would make a detailed multi-regional I-O or CGE analysis problematic. Second, the deficiencies in a partial equilibrium model vis-à-vis an I-O or CGE model in the context of animal disease are unlikely to have serious consequences in the current context. While partial equilibrium models do not have the analytical power to examine changes in employment and non-agricultural sectors, these issues are less important in South America than the detailed sectoral impacts provided in a partial equilibrium model, given that the impact of an outbreak would be felt primarily among livestock producers and processors. National employment impacts from an FMD outbreak would likely be modest and temporary, and any national decline in employment in livestock production would be offset by a corresponding increase in government spending to combat the outbreak. Any effects on capital and foreign exchange markets would also be short-lived. Non-agricultural impacts could be measured with an I-O table, using shocks from the agricultural sector that were obtained from the multimarket analysis.

Model Specification

The model is comprised of five blocks of equations: supply, demand, income, prices, and trade. The first and second block of equations denotes the supply and demand relationships for meat, livestock, and feedgrains. The model is set up in a vertically integrated system using the equation specification of Jeong et al. (2003), with the exception that fed cattle is not modeled due to data limitations. Moreover, all supply and demand equations are modeled as double-log, constant elasticity functions. A vertically integrated system has been used in other partial equilibrium formulations (Mangen et al., 2002). However, DISCOSEM is unique in modeling all major meat sectors in addition to related feed markets.

Major input (feed) markets in the model include corn and soybeans. Other inputs, such as hay and pasture, which may be important in cattle production are not currently modeled due to lack of data. Equation (1) specifies corn and soybean supplies (S^c) at time t in region r as functions of their own producer price (pp); land, fertilizer, and labor markets are not modeled explicitly and thus not included in the specifications of these markets. Crop demand (D^c) is modeled as a function of its own consumer price (pc), the consumer price of substitute feeds, the producer price of meat (pp^m, where m is pork or lamb), and the producer price of slaughter livestock (pp^l, where l is beef cattle):

$$S_{t,r}^{c} \equiv S_{t,r}^{c}(pp_{t,r}^{c}), c \in \{corn, soybeans\} \quad (1)$$

$$D_{t,r}^{c} \equiv D_{t,r}^{c}(pc_{t,r}^{corn}, pc_{t,r}^{soy}, pp_{t,r}^{m}, pp_{t,r}^{l}), m \in \{pork, lamb\}, l \in \{cattle\} \quad (2)$$

The three equations for animal inventories and slaughter cattle markets specify the dynamics of investment and consumption behavior in the live animal markets; this reflects the view of cattle (and other livestock) as both consumption and investment goods as characterized by Jarvis (1974, 1986). Following Jeong et al. (2003), cattle inventories (*INV*) are modeled in equation (3) as a function of the lagged producer price of slaughter cattle and the one-period lagged supply of beef calves. The supply of slaughter (S^{sl}) will depend on current cattle inventory, lagged supply of slaughter cattle, the producer price for steers, and the consumer price of corn.[5] While corn is not a major input to cattle production, it is included to capture the increasing use of feedlot production, particularly in Argentina. This inclusion of animal inventories and live animal markets enables DISCOSEM to examine the role of long-term investment on welfare. The approach extends past multimarket models (Braverman et al., 1987; Goletti and Rich, 1998) which have characterized livestock models in a much simpler manner. Demand for slaughter cattle (D^{sl}) is a function of current slaughter prices at the consumer level, lagged demand, and the producer price for high-quality (*HQ*) and low-quality (*LQ*) beef.

$$INV_{t,r} \equiv INV_{t,r}(pp_{l_{t-1,r}}, Q^{calves}_{t-1,r}) \quad (3)$$
$$S^{sl}_{t,r} \equiv S^{sl}_{t,r}(S^{sl}_{t-1,r}, pp^{sl}_{t,r}, pc^{corn}_{t,r}, INV_{t,r}) \quad (4)$$
$$D^{sl}_{t,r} \equiv D^{sl}_{t,r}(D^{sl}_{t-1,r}, pc^{sl}_{t,r}, pp^{HQ}_{t,r}, pp^{LQ}_{t,r}) \quad (5)$$

Meat supply (S^m equation 6) is modeled on the basis of own meat price, input prices for live animals (in the case of beef), feed prices (for pork), and lagged supply of livestock/meat. In the beef market, supply is converted from live weight to retail cuts based on slaughter and technical conversion factors; thus carcass and slaughter markets are not directly modeled. Meat demand (D^m in equation 7) is modeled as a function of own consumer price, the consumer price of substitutes, and income per capita (YPC).

$$S^m_{t,r} \equiv S^m_{t,r}(S^m_{t-1,r}, pp^m_{t,r}, pc^{corn}_{t,r}, pc^{soy}_{t,r}, pc^{sl}_{t,r}), m \in \{pork, lamb, HQbeef, LQbeef\} \quad (6)$$
$$D^m_{t,r} \equiv D^m_{t,r}(pc^{HQ}_{t,r}, pc^{LQ}_{t,r}, pc^{pork}_{t,r}, pc^{lamb}_{t,r}, YPC_{t,r}), m \in \{pork, lamb, HQbeef, LQbeef\} \quad (7)$$

Three inequalities determine the movement of prices in the model. In the domestic market, the producer price (*pp*) of a commodity *g* in region *r* plus transportation costs (*TC*) and margins (*MARGD*) must be at least as large as the consumer price (*pc*) in region *rr*; if the constraint is binding, there will be trade between region *r* and region *rr*: Likewise, the consumer price must be less than or equal to the import price (*pm*) plus transportation costs and import margins (*MARGM*), while the export price (*px*) should be less than or equal to the producer price plus transport costs and export margins

(*MARGX*). If either equation is binding, there will be entry of (respectively) imports and exports into the system, viz.:

$$pp_{t,r}^{g} + TC_{t,r,rr}^{g} + MARGD_{t,r}^{g} \geq pc_{t,rr}^{g} \quad (8)$$

$$pc_{t,r}^{g} \leq pm_{t}^{g} + TC_{t,r}^{g} + MARGM_{t,r}^{g} \quad (9)$$

$$px_{t}^{g} \leq pp_{t,r}^{g} + TC_{t,r}^{g} + MARGX_{t,r}^{g} \quad (10)$$

Inflows and outflows of commodities across regions are regulated by equations 11 and 12. First, total demand (*D*) from region *r* must not exceed total imports (*I*) to region *r* from the rest-of-the-world and the sum of trade (*TQ*) from all other regions (*rr*) to region *r*. Second, total supply must be at least as large as total exports (*X*) from region *r* to all other regions (*TQ*) plus exports abroad:

$$TQ_{t,rr,r}^{g} + I_{t,r}^{g} \geq D_{t,r}^{g} \quad (11)$$

$$S_{t,r}^{g} \geq TQ_{t,r,rr}^{g} + X_{t,r}^{g} \quad (12)$$

The final block of the model is the income block, which, for each region, is simply the sum of agricultural income per capita plus exogenous non-farm income per capita (*NFYPC*). Farm income is defined as the net sum of revenue for each product:

$$YPC_{t,r} = NFYPC + (pp_{t,r}^{m} S_{t,r}^{m} + pp_{t,r}^{sl} S_{t,r}^{sl} + pp_{t,r}^{c} S_{t,r}^{c} - pc_{t,r}^{sl} D_{t}^{sl} - pc_{t,r}^{c} D_{t,r}^{c}) / POP \quad (13)$$

As mentioned earlier, DISCOSEM is solved in GAMS using the MCP solver; thus no objective function is required, provided the model is specified with an equal number of equations and unknowns and properly defined complementarity conditions. Dynamics are simulated by solving the model recursively (Day and Cigno, 1978).

Data

A major challenge in calibrating DISCOSEM is that some of the regional data for Argentina and national data for Paraguay are not available. National data were use to construct regional databases in many instances. While these data are imperfect, they allow us to demonstrate the methodology and provide illustrative results.

Baseline data on production for livestock and crops are from the Ministries of Agriculture of Argentina, Uruguay, and Paraguay. These data included information on animal demographics, the number of animals slaughtered, and, for Argentina and Uruguay, statistics on the average carcass weight for slaughtered animals; FAO data were used in the case of Paraguay for average carcass weight and slaughter and for data on pork and lamb production for Uruguay and Paraguay.

Statistics on prices were more problematic. In the case of Argentina, monthly time series data are available for slaughter price of animals by age category (calves, steers, heifers, cows, and bulls) for the Liniers market, which is the largest auction yard in Argentina. However, regional data on slaughter prices are not consistently available. For instance, the website for SAGPyA (Ministry of Agriculture, Livestock, and Fisheries) in Argentina contains sporadic information on slaughter and fed cattle prices for certain districts on a monthly basis, but the frequency of updates is inconsistent. Moreover, time series data of this nature are not easily available. Preliminary analysis of data collected for 2003 suggests that the slaughter prices of outlying regions (Patagonia/Cuyo and the North) are slightly lower than the Liniers price. For the purposes of the model, the Patagonia/Cuyo price is assumed to be 10 percent lower than the Liniers price (used to proxy the Pampas price), while the price in the North is assumed to be 5 percent lower. Slaughter prices were available for Uruguay, but not Paraguay. Anecdotal evidence suggests that the live animal prices in Paraguay are significantly lower than those in Argentina; in 2003, a press article reported that prices in Paraguay were 40 percent lower than those in Argentina. Therefore, the live animal price for Paraguay was assumed to be 40 percent lower than the price in the North.

Data on demand and retail prices were of varying quality. For Argentina, detailed information on retail price by type of beef cut by region was recovered from the 1996/97 Household Survey conducted by INDEC. Using this data and insights from experts at the University of California, Davis, cuts of beef were aggregated into high and low quality components and average prices computed for each region. These prices were converted to 1999 prices using data on consumer price inflation by food product. For Uruguay, retail prices for four different cuts were available from the Ministry of Agricultural, Livestock, and Fisheries, and categorized into high and low components, respectively. Data on per capita consumption for Argentina was calculated from the INDEC household survey. Per capita consumption for Uruguay and Paraguay was derived as the residual from food availability (production plus imports less exports).

Elasticities are to be econometrically estimated based on information from the household survey and time-series data on livestock and feed crops. For the time being, elasticities for livestock and meat products are based on Jeong et al. (2003).[6]

Simulation analysis

The structure of DISCOSEM is amenable to the analysis of alternative disease mitigation strategies. In the literature, conventional analyses have either used an epidemiological model to calibrate the disease shock (Berentsen et al., 1992; Garner and Lack, 1995; Ekboir, 1999; Schoenbaum and Disney, 2003) or have simply assumed exogenous shocks that would correspond to a disease outbreak (O'Toole et al., 2002). For the purposes of illustrating the methodology of DISCOSEM, the latter approach is applied here; however, this model can easily be adapted to calibrate shocks with a suitable epidemiological model of disease spread.[7]

Two simulations are presented to demonstrate alternative disease mitigation strategies presented to policymakers. In the first scenario, an FMD outbreak is assumed to occur throughout the Southern Cone and is combated through a mass vaccination policy; this is similar to what occurred in 2001. The outbreak occurs in year 2 of the five-year period and is assumed to reduce exports to 60 percent of their value in the previous year, due to export bans by major trading partners. This figure is based on approximate levels of exports during the 2001 outbreak. In the following year (year 3), some FMD-free (with vaccination) markets are open. However, the result of a mass vaccination strategy is that FMD-free without vaccination markets (and some FMD-free with vaccination markets) are closed and thus the average price of exports received by exporters will be lower in subsequent years. In years 3 and 4, a 25 percent drop in the export price is assumed; this is roughly analogous to the price change experienced in 2002 by Uruguay after the FMD outbreak. In the final year (year 5), export prices recover to 90 percent of their former value as markets such as the United States are assumed to open; Japan and Korea remain closed. The first scenario also assumes that there is no productivity effect as a result of the FMD outbreak. This is plausible, given that in Argentina in 2001, less than 0.5 percent of all animals were infected by FMD (even in the Pampas, the figure was less than 1 percent). Vaccination and administration costs are estimated at 90 cents per animal per year (Rich, 2004).

In the second scenario, a stamping out strategy is imposed. In a stamping out strategy, all infected and contact herds are culled and indemnity payments are made to producers by the government. As an illustration, it is assumed that 5 percent of the herds in the Southern Cone are slaughtered; this corresponds to the number of animals that were exposed to FMD in Argentina during the 2001 outbreak. Indemnity payments are made on the basis of the slaughter value of the animal ($287, based on the average price and live weight for animals sold to the Liniers auction yard in Argentina).[8] Remaining herds are vaccinated in the outbreak year only (2 doses). As with the first scenario, the outbreak takes place in year 2 and exports are limited to 60 percent of their previous level. In year 3, exports are again open to some FMD-free (with vaccination) markets, but at a lower export price (75 percent of the former world price). In year 4, it is assumed that more FMD-free markets open due to the stamping out policy and cessation of vaccination in the previous year; thus the export price rises to 90 percent of its original value. In the final year, all markets are open to meat from the Southern Cone and the export price reverts back to the original, pre-outbreak level.

Preliminary results are summarized in tables 1 and 2. The results suggest that a stamping out policy would have a net present value of over $1 million over a five-year period relative to a vaccination-only strategy, primarily due to the higher prices received on domestic and export markets due to a stamping out policy. In a vaccination control strategy, inventories of animals rise due to lower prices on both domestic and exported meat. Exports only gradually rise after the outbreak, due to dampened price incentives. The value of slaughter animals falls as a result of the increased inventories of animals; net revenue in meat markets is slightly higher relative to the stamping out strategy because input costs (slaughter animals) are lower. By contrast, a stamping out policy reduces stocks of animals and while prices fall, due to the lower prices on world markets, they do not fall as much, given that inventories have been decreased. Exports initially fall after the outbreak, due to lower inventories, but rise sharply in response to higher price incentives provided by the faster opening of higher-value, FMD-free markets.

The stamping out policy dominates when all regions are considered as a group, but a regional disaggregation reveals differences over space. The simple simulation applied here assumed that the FMD outbreak occurs simultaneously and with equal intensity in all parts of the Southern Cone. Even under these unlikely conditions, Table 3 indicates that the vaccination approach is superior in Paraguay while stamping is preferable in each of the regions of Argentina and in Uruguay. The difference arises from lower prices and export volumes in Paraguay, which makes the high cost of stamping out unwarranted. Higher incidences of FMD could also make stamping out less attractive. Thus different spatial distributions of the intensity of outbreaks could be expected to yield different strategies across the regions.

A number of caveats should be given to the preliminary analysis above. First, export prices are assumed to remain constant in the scenarios, which is not realistic. A small country assumption is also maintained, which may not be suitable for the Southern Cone in meat markets.[9] The simulations also consider a “perfect” stamping out policy in which countries of the Southern Cone remain FMD-free without vaccination after an outbreak. However, such a scenario is contingent on the disease status of neighboring and nearby countries (Bolivia, Peru, Brazil). Recent outbreaks that occurred in Argentina and Paraguay in 2003 despite vaccination demonstrate that a pure stamping out policy may not be realistic at this stage.

Conclusions

The impacts of disease vary over time and space. The preceding multimarket analysis illustrates how the economics of animal disease can be examined in a way that captures both temporal and spatial factors. In the scenarios for FMD control presented above, a stamping-out policy was shown to have a larger net present value over a five-year period than a vaccination-only strategy; however, such a policy might not be viewed as optimal in a short-run framework. Multi-period analysis that focused on the epidemiological progression of FMD but failed to capture economic behavior concerning inventories would also misrepresent the evolution of costs and benefits over time. The simulation applied in this analysis was not spatial from an epidemiological perspective, but the model still revealed economic impacts that varied by region. Moreover, the DISCOSEM model used can accommodate spatial variation in the disease shock itself. Future research will examine, for example, the role of an isolated, regional outbreak on the dynamics of intra- and inter-regional trade and production. This represents a significant methodological advantage over past models by identifying regional approaches to disease control that may differ from national-level strategies.

The specific results of this analysis must be viewed as illustrative, rather than conclusive at this point. The results assume that both vaccination and stamping out could be implemented perfectly and that there are no spillover effects from neighboring or nearby regions. Under these circumstances, the strategy in one country is fully separable from that chosen in any other. However, as demonstrated in Rich and Winter-Nelson (2004b), regional externalities can play a significant role in explaining the persistence of the FMD in Latin America. This implies the need to capture such exogenous regional effects in determining the "best" type of intervention.

The tendency of FMD to spread rapidly over space suggests that disease control efforts need to be carried out in a continent-wide approach rather than on a sub-regional basis. While there is a need for central coordination, the results of this analysis illustrate a need for sensitivity to regional diversity. Optimal control strategies will vary within the continent. To the extent that a given control strategy is implemented fully and effectively, the diversity in approaches need not undermine efficacy in any given sub-region. However, when one strategy is more prone to failure, or when some countries find tolerance of FMD to be superior to control, an international public goods problem arises. In these cases, incomplete or absent disease control in one country will undermine control efforts in all others. Spatial analysis can again play a role in determining what international transfers or controls can address the spillover effects.

Table 1: Results of a vaccination-only strategy in the Southern Cone

Year	Exports ('000 tons)	Export price (USD/t)	Export Value ('000 USD)	Discounted Export Value (5% discount rate)	
1	566.726	3,650	2,068,550	2,068,550	
2	275.000	3,650	1,003,750	955,952	
3	260.472	2,737.5	713,042	646,750	
4	255.215	2,737.5	698,651	603,521	
5	460.209	3,285	1,511,787	1,243,751	
GROSS INCOME (EXPORTS)				**5,518,524**	
Year	Value of slaughter cattle ('000 USD)	Net revenue from beef ('000 USD)	Total product value ('000 USD)	Discounted product value (5% discount rate)	
1	3,950,894	341,302	4,292,196	4,292,196	
2	3,523,127	(666,237)	2,856,890	2,720,848	
3	3,390,581	(575,458)	2,815,123	2,553,400	
4	3,353,515	(483,625)	2,869,890	2,479,119	
5	3,574,879	317,917	3,892,796	3,202,613	
GROSS INCOME (DOMESTIC BEEF)				**15,248,175**	
Year	Animals culled ('000 head)	Animals vaccinated ('000 head)	Cost per vaccination (USD/animal)	Total cost ('000 USD)	Discounted Cost (5% discount rate)
1	0	78,315	0	0	-
2	0	82,801	0.9	74,521	70,972
3	0	88,444	0.9	79,600	72,199
4	0	91,118	0.9	82,006	70,840
5	0	92,049	0.9	82,844	68,156
GROSS COSTS					**282,168**
NET BENEFIT (VACCINATION-ONLY)					**20,484,531**

Source: Model simulations

Table 2: Results of a stamping-out strategy in the Southern Cone

Year	Exports ('000 tons)	Export price (USD/t)	Export Value ('000 USD)		Discounted Export Value (5% discount rate)	
1	566.726	3,650	2,068,550		2,068,550	
2	275.000	3,650	1,003,750		955,952	
3	191.296	2,737.50	523,673		474,987	
4	385.335	3,285.00	1,265,825		1,093,468	
5	473.180	3,650	1,727,107		1,420,895	
GROSS INCOME (EXPORTS)					**6,013,852**	
Year	Value of slaughter cattle ('000 USD)	Net revenue from beef ('000 USD)	Total product value ('000 USD)		Discounted product value (5% discount rate)	
1	3,950,895	341,302	4,292,197		4,292,197	
2	3,796,972	(752,208)	3,044,764		2,899,775	
3	3,713,683	(890,374)	2,823,309		2,560,824	
4	3,947,830	(167,397)	3,780,433		3,265,680	
5	4,165,504	315,154	4,480,658		3,686,248	
GROSS INCOME (DOMESTIC BEEF)					**16,704,725**	
Year	Animals culled ('000 head)	Animals vaccinated ('000 head)	Indemnity Costs (USD/animal)	Cost per vaccination (USD/animal)	Total cost ('000 USD)	Discounted Cost (5% discount rate)
1	0	78,315	0	0	0	-
2	3916	74,026	287	0.9	1,190,444	1,133,756
3	0	74,768	0	0	0	-
4	0	75,701	0	0	0	-
5	0	73,569	0	0	0	-
GROSS COSTS						**1,133,756**
NET BENEFIT (STAMPING OUT)						**21,584,821**

Source: Model simulations

Table 3: Net Present Value of Disease Control Strategy by Region (‘000 USD)

Region	Vaccination	Stamping Out	Percent difference (Stamping Out/Vaccination)
Patagonia/Cuyo	583,992	604,931	3.6%
Pampas	13,222,367	14,037,994	6.2%
North of Argentina	2,283,401	2,395,382	4.9%
Uruguay	3,599,136	3,770,471	4.8%
Paraguay	795,630	776,028	-2.5%
TOTAL	20,484,526	21,584,807	

Source: Model simulations; totals may not add up due to rounding.

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End Notes

[1] In addition, countries that are FMD-free have more flexibility in marketing certain types of cuts to diverse markets.

[2] Neither Argentina nor Paraguay is recognized by the OIE as being FMD-free with vaccination, due to outbreaks in 2003 and 2002, respectively. Uruguay, on the other hand, has been recognized by the OIE as FMD-free with vaccination since May 2003 and has been able to market many (but not all) types of beef exports to most major markets except Japan, Korea, and Mexico.

[3] While sheep and pigs are susceptible to FMD, vaccination programs in the Southern Cone have only been prescribed for cattle.

[4] Dairy products are currently excluded from the model, despite the productivity effects an FMD outbreak can have on this sector. Future work will attempt to incorporate this sector.

[5] The Jeong et al. (2003) specification includes expectations about prices; this is not modeled in this framework.

[6] Econometric estimates for the elasticities of the model are pending and will be presented in August. Jarvis (1974, 1986) has a number of detailed models of the livestock sector in Argentina, but does not provide sample means to compute elasticities with his linear model, thus precluding the use of his results.

[7] In fact, DISCOSEM has been designed with a spatial epidemiological model based on the state-transition model of Durand and Mahul (2000); simulation results based on the combination of the epidemiological model with the multimarket model will be presented in August.

[8] This figure is likely high. In the Artigas outbreak in Uruguay, the average indemnity payment per animal was $175. However, the majority of those animals were sheep, which fetch a lower value than beef cattle.

[9] Indeed, it is likely more appropriate to model the Southern Cone as a large country, since the experience of Argentina and Uruguay after the FMD outbreak of 2001 was a return to pre-outbreak levels of exports the following year, albeit at a much lower export value.