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DISCOSEM: An Integrated Epidemiological-Economic Analysis of Foot and Mouth Disease in the Southern Cone

by

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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, or "Mad Cow" Disease) in cattle in the United States resulted in the immediate closure of almost 90 percent of the U.S. export market for beef. 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, the 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 across space. 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 role of investment in livestock economics. In light of these issues, this paper develops an integrated epidemiological-

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economic model of animal disease control (DISease COntrol Spatial Epidemiological-economic Model, DISCOSEM) that, in contrast to the existing literature, is both dynamic and spatial. The model is intended to support analysis of alternative FMD control policies in the Southern Cone.[2]

The spatial component of the epidemiological model represents an improvement over past models of FMD (Berentsen, *et al.*, 1992; Garner and Lack, 1995; Ekboir, 1999; Durand and Mahul, 2000), with the added advantage of being linked to a spatial economic model that can determine the regional effects from different mitigation strategies. Moreover, the dynamic nature of the economic component is significantly different from past economic models of FMD control and represents a methodological improvement. Previous partial-equilibrium models have either been static (one-period) or short-run analyses that measured the short-run shocks to supply, productivity, and exports (Schoenbaum and Disney, 2003; Mangen, *et al.*, 2004). Others have attempted to incorporate dynamics but 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, which in turn will have welfare impacts in the economy over time, a dynamic approach is suggested to capture these effects, as well as the dynamics of disease itself.

Twelve different control strategies are considered based on the simulation results of the epidemiological component applied to an initial outbreak in Paraguay. The model results are combined with exogenous costs such as vaccination and eradication costs, veterinary services, and other government expenditures to determine the total benefits and costs of an outbreak over a five-year period under alternative mitigation strategies. Preliminary results from the model indicate that stamping out strategies have greater long-term benefits than policies that utilize vaccination, given that stamping out policies engender shorter dislocations on international markets than vaccination policies. Moreover, policies that combine vaccination in Paraguay and stamping out elsewhere were shown to have the highest net benefits, given that such a combined policy led to slightly shorter outbreaks and was less costly than pure stamping out. Prophylactic, preventative vaccination by nearby regions (i.e., vaccinating upon discovery of the disease in Paraguay) was the most effective strategy from an epidemiological standpoint and was the best

[2] The Southern Cone is defined as Argentina, Uruguay, Paraguay, and Southern Brazil.

short-term policy, but resulted in reduced benefits over time, given the disruption vaccination policies have on accessing export markets.

One should observe caution from these results, since the benefits from any disease control effort depend substantially on the ability of neighboring countries to effectively control disease and may mitigate a successful stamping-out policy (Rich, *et al.*, forthcoming). These results thus suggest a coordinated multinational approach toward disease control. More importantly, this paper demonstrates the utility of an integrated epidemiological-economic model to facilitate the spatial analysis of disease control by measuring sector and welfare impacts while capturing market and disease dynamics in a more precise way than most approaches allow.

An Overview of FMD

FMD 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 of age is significantly higher; in 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, consequently 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 is much greater than these productivity effects might suggest because of the impact of the disease on market access in international beef markets. Given the rapid spread and high containment costs associated with FMD, countries that are FMD-free (as designated by the International Office of Epizooties, or OIE) restrict imports of meat from countries that are not FMD-free, with trade limited to certain types of meat (e.g., processed meat). Sanitary restrictions on trade thus create a segmented market in which fresh meat exports 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).[3] Moreover, certain high-value international markets, such as Japan and Korea, make a further distinction in commerce between FMD-free countries in which vaccination is practiced and those that are FMD-free without vaccination, since it is difficult to ascertain the difference between meat from an infected animal versus one that has been vaccinated and generated an immune response to the disease (Rich, 2004). This "zero-risk policy" restricts meat imports in these markets from all but FMD-free without vaccination 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 have struggled over the past century to eradicate FMD from their cattle herds. After the region 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.[4]

FMD control strategies vary by country and context. A stamping out policy involves the slaughter of infected herds and herds in direct contact with infected herds, usually defined by those within a pre-set radius from the infected herds. Ring vaccination is sometimes conducted in conjunction with a stamping out policy for herds outside the control zone to create a buffer area to further control the spread of disease. Movement controls are also implemented. A pure stamping out approach is to be followed in the case of an outbreak in the United States, though vaccination can be adopted under certain conditions (Ekboir, 1999). In countries where FMD is endemic, vaccination is the primary control strategy, with contact slaughter and additional ring vaccination used to control specific outbreaks. 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 in Southern Africa until recently, when FMD outbreaks breached the FMD control zones in

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

[4] 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.

Zimbabwe and South Africa. In the Southern Cone, vaccination was employed to eradicate the disease in 1990s, after which time stamping out was to be 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.[5]

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 to assess the costs and benefits of alternative strategies (Miller, *et al.*, 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, *et al.*, 2004). However, 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 benefit-cost models, several methodological approaches have been used in more recent disease control models; a thorough review can be found in Rich, *et al.* (2004). Several studies have used input-output (I-O) models (or social accounting matrices) to derive sectoral multipliers, which measure the economy-wide impact of a final demand shock in the livestock sector caused by a disease outbreak (Garner and Lack, 1995; Caskie *et al.*, 1999; Ekboir, 1999; Mahul and Durand, 2000). Typically, multipliers are computed for labor markets, households, and livestock and related sectors. An epidemiological model is usually used to calibrate the size of the shock, which is used 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; indeed, livestock supply may be predetermined (Eales and Unnevehr, 1993). Moreover, the

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

nature of most animal diseases represents both a supply shock and a demand shock. (BSE is an important exception). As a result, past studies likely overstate the impact of disease outbreaks (Sadoulet and de Janvry, 1995). Secondly, previous studies have failed to calculate the net impact of a disease, since an outbreak can generate employment and income in other sectors (e.g., government) depending on the mitigation strategy that can partially balance the negative impact of the disease. Rich (2003) uses an empirical model of FMD control in Zimbabwe that incorporates supply constraints in the livestock sector to illustrate the magnitude 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) 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 one calibrated from a formal 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 social accounting matrix 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 in animal health applications. Mangen, *et al.* (2004) used a vertically-integrated model of the hog industry in the Netherlands to analyze of Classical Swine Fever in the Netherlands; related input and output markets were not used in their 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, the structure of DISCOSEM is provided to illustrate the specification of an integrated epidemiological-economic model of animal disease control. The economic component of the model resolves many of the shortcomings of past economic analyses by using a partial-equilibrium, multi-market model of animal disease control that is both dynamic and spatial.

Structure of DISCOSEM

Epidemiological model[6]

The disease control portion of DISCOSEM is grounded in standard veterinary epidemiological models used in the analysis of FMD. Specifically, a state-transition model is used (Daley and Gani, 1989). Briefly, a state-transition model is a system of differential equations (or first-difference equations if discrete time is used) that represents the transition of animals between different stages of disease. The most prevalent type of state-transition model used for FMD is an S-I-R model, which has three states (Susceptible, Infected, and Removed). Animals move between the Susceptible to Infected and Infected to Removed states based on transition rates that are either assumed from past studies or calibrated from past outbreaks (Miller, 1979; Berentsen, *et al.*, 1992; Garner and Lack, 1995; Ekboir, 1999; Durand and Mahul, 2000; Schoenbaum and Disney, 2003). In discrete time, a state-transition model is derived from a Markov Chain and uses transition probabilities to characterize the movement of animals between states (Garner and Lack, 1995). The S-I-R system is usually closed such that $S + I + R = N$, where N is the total number of animals in the system. Equation (1) characterizes the simple S-I-R system; the parameters β and α represent the transition rates from Susceptible to Infected and Infected to Removed, respectively:

$$\begin{aligned} \frac{dS}{dt} &= -\beta SI \\ \frac{dI}{dt} &= -\alpha I + \beta SI \\ \frac{dR}{dt} &= \alpha I \end{aligned} \qquad (1)$$

Models of FMD control have often modified the S-I-R system of (1) to incorporate additional states (Ekboir, 1999; Durand and Mahul, 2000; Schoenbaum and Disney, 2003). For instance, the Removed state can be partitioned into the states Immune (to incorporate vaccine response)

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[6] More detail on the epidemiological model can be found in Chapter 3 of Rich (2005).

and Dead (to reflect animals that have been culled or died from the disease), while the Infected state can be sub-divided to reflect periods of disease latency or exposure.

In conventional models, the study area is assumed to be radial, with the radius predetermined based on the characteristics of the disease control program (most studies assume a 10-30 km radius). Some models assume two radial areas, with the outer area representing a buffer vaccination zone. All animals (or herds[7]) in the circle are assumed to be susceptible, with one animal (or herd) assumed to be infected at time $t = 1$. The S-I-R model is then run based on the assumed or estimated transition rates. Different mitigation strategies (vaccination, stamping out) are simulated based on changes in the magnitude of the transition rates and sequencing of other exogenous parameters.

DISCOSEM is based on a modification of the FMD model of Durand and Mahul (2000) (hereafter, DM). Unlike most conventional state-transition models of disease control, the DM model incorporates the spatial spread of disease within a particular region. In the DM model, two radial areas are assumed: an inner-ring with a radius of 10-km and an outer ring with radius 5-km. Animals in the inner ring are designated as in the state "Susceptible-Exposed" (S), while animals in the outer ring are in the state "Susceptible-Not Exposed" (SN). In each time period, each ring is assumed to grow by 1 km, with some animals from the SN state moving to the state S, while some animals from outside the ring move into the SN state. Thus, unlike a conventional S-I-R model, the DM model is not closed. The DM model also further subdivides the Infected state into Incubating (or latent), Invasion, and Clinical states and the Removed state into Immune and Dead states.

While the DM model is useful in modeling spatial spread within a region, it does not explicitly handle inter-regional spread of disease. However, a simple modification to the S-I-R framework can be used that incorporates spatial spread. Rushton and Maunter (1954) first modified the S-I-R model to examine mixing between heterogeneous populations by simply adjusting the βSI term such that it incorporates the movement of infecteds from within one's own region (say,

[7] In some models, including DISCOSEM, the unit of measurement is the herd rather than the animal, such that if one herd is infected, it is assumed that all animals in that herd are also infected.

region *i*) and from regions $j = 1 \ldots k,\ i \neq j,$ to region *i*. A similar framework was used by Howe *et al.* (2003) in a model of Bovine Malignant Catarrhal Fever in Tanzania.

$$
\begin{aligned}
\frac{dS_i}{dt} &= -\beta_{ii} S_i I_i - S_i \sum_{\substack{j=1 \\ j\neq i}}^{k} \beta_{ji} I_j \\
\frac{dI_i}{dt} &= -\alpha_i I_i + \beta_{ii} S_i I_i + S_i \sum_{\substack{j=1 \\ j\neq i}}^{k} \beta_{ji} I_j \qquad (2) \\
\frac{dR_i}{dt} &= \alpha_i I_i
\end{aligned}
$$

The epidemiological portion of DISCOSEM is programmed in STELLA (version 7.0.3) and its schematic is presented in Figure 1. While complicated on first glance, the diagram illustrates the structure of the model. The parameters in the dark circles represent the stocks of animals in each of the seven states of the model (Susceptible-Exposed, Susceptible-Not Exposed, Incubation, Invasion, Clinical, Immune, and Dead). Parameters in the rectangular shapes are the flows of animals between states. As DISCOSEM is a discrete-time model (using one-week time steps[8]), transition probabilities are used to characterize movements between states; in the diagram, these probabilities are highlighted by the pentagonal shapes. The parameter p_{si} (transition probability from susceptible-exposed to incubation) parameter in the model is analogous to the β parameter in the continuous time model and is a function of the dissemination rates (DRs) from each region (10 in total: 8 in Argentina, Uruguay, and Paraguay). For region *i*, the probability of moving from susceptible-exposed to incubation is a function of internal spread within region *i* and imports of animals from each region to region *i*. Note that only adjacent regions are assumed to contribute to the spread of disease for a given region (some links will thus be zero). Moreover, it is assumed that trade between certain regions is stochastic and may or may not occur in each period. Terms that are highlighted with octagonal shapes represent parameters that are either specific to the disease control strategy modeled (alpha, delta) or are

[8] This is contrast to Durand and Mahul (2000) who use time steps of 0.5 weeks.

triggers to turn on or off certain parameters depending on the evolution of disease. Parameters highlighted with light oval shapes characterize the movement of the radial area over time.[9]

Economic model

Overview

The economic component of DISCOSEM is based on spatial equilibrium models developed in the Markets and Structural Studies Division at the International Food Policy Research Institute (IFPRI) in the late 1990s (Goletti and Minot, 1998). DISCOSEM employs a solution technique known as mixed complementary programming (MCP) that is commonplace in the solution of CGE models. 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 movements 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, $f(x) \geq 0$ 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 the MCP approach 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

[9] Parameters that are repeated in the diagram are referred to in STELLA as “ghosts”, which are simply used to ease exposition by reducing the number of arrows represented in the diagram.

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.

The economic component concentrates on modeling phenomenon in the agricultural side of the economy. A total of six economic sectors are modeled: cattle, beef, pork, lamb, corn, and soybeans; cattle inventories are also included.[10] 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 in terms of investment and animal inventories resulting from an outbreak. The model is solved recursively, in which changes to animal inventories, population, and per capita income drive the data generating process for each period (Day and Cigno, 1978). The dynamic, long run nature of the model thus distinguishes it from past models of FMD control. 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 three regions of Argentina in the economic model are aggregates of the eight epidemiological study regions. 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 income, as well as to model the differential effects of 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 exclude many possible economic linkages and should be viewed as a first-round approximation

[10] Dairy products are currently excluded from the model, despite the productivity effects an FMD outbreak can have on this sector.

to the "true" impacts of any simulated shocks. Nonetheless, the choice of a partial equilibrium model over other multisectoral approaches (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-sector model 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 a current input-output table exists for Paraguay. More importantly, the lack of commonality among sectors in different I-O tables would make a detailed multi-regional I-O or CGE analysis problematic. Secondly, the deficiencies of 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 (Rich, Miller, and Winter-Nelson, 2004), these issues are less important in South America than the detailed sector-level 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.

Economic model specification

The economic model is comprised of five blocks of equations: supply, demand, income, prices, and trade. The first and second block of equations denote the supply and demand relationships for meat, livestock, and feedgrains. The model is set up as a vertically integrated system using the equation specification of Jeong *et al.* (2003), with the exception that the fed cattle market is not modeled due to data limitations. Also, 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 applied to animal disease control (Mangen, Burrell, and Mourits, 2004). However, DISCOSEM is unique in this sense by modeling all major meat sectors in addition to related feed markets. A diagram of the partial-equilibrium multimarket framework of the model is presented in figure 2.

The input markets in the model include corn and soybeans, which are used for feed. Other inputs, such as hay and pasture which are important in the production of cattle, are not currently modeled due to lack of data. Likewise, land, fertilizer, and labor markets are also not included as input markets. The equations in (3) specify corn and soybean supplies (*S*) at time *t* in region *r* as functions of their own producer price (*pp*). Crop demand (*D*, equations in (4)) is modeled as a function of its own consumer price (*pc*), the consumer price of substitute feeds, the producer price of pork (pp^{pork}), and, in the case of corn, the producer price of slaughter livestock (pp^{sl}):

$$\begin{aligned} S_{t,r}^{corn} &\equiv S_{t,r}^{corn}(pp_{t,r}^{corn}) \\ S_{t,r}^{soy} &\equiv S_{t,r}^{soy}(pp_{t,r}^{soy}) \end{aligned} \qquad (3)$$

$$\begin{aligned} D_{t,r}^{corn} &\equiv D_{t,r}^{corn}(pc_{t,r}^{corn}, pc_{t,r}^{soy}\, pp_{t,r}^{pork}, pp_{t,r}^{sl}) \\ D_{t,r}^{soy} &\equiv D_{t,r}^{soy}(pc_{t,r}^{corn}, pc_{t,r}^{soy}\, pp_{t,r}^{pork}) \end{aligned} \qquad (4)$$

The three equations for animal inventories and slaughter cattle markets specify the dynamics of investment and consumption behavior in live animal markets; this reflects the view that cattle (and other livestock) are both consumption and investment goods as characterized by Jarvis (1974, 1986). Following Jeong *et al.* (2003), cattle inventories (*INV*) are modeled in equation (5) as a function of the one-period lagged producer price of slaughter cattle and the one-period lagged supply of (exogenous) beef calves. The supply of slaughter cattle (S^{sl}) will depend on current cattle inventory, lagged supply of slaughter cattle (reflecting a partial adjustment process), the producer price for steers, and the consumer price of corn.[11] 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 and thus extends past multimarket

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

models (Braverman *et al.*, 1987; Goletti and Rich, 1998) that have characterized livestock markets 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.

$$INV_{t,r} \equiv INV_{t,r}(pp^{sl}_{t-1,r}, Q^{calves}_{t-1,r}) \quad (5)$$

$$S^{sl}_{t,r} \equiv S^{sl}_{t,r}(S^{sl}_{t-1,r}, pp^{sl}_{t,r}, pc^{corn}_{t,r}, INV_{t,r}) \quad (6)$$

$$D^{sl}_{t,r} \equiv D^{sl}_{t,r}(D^{sl}_{t-1,r}, pc^{sl}_{t,r}, pp^{HQ}_{t,r}, pp^{LQ}_{t,r}) \quad (7)$$

For pork and lamb, meat supply (equations in 8) is modeled on the basis of lagged supply and the own producer price of meat. The pork market is also a function of feed prices (corn and soybeans). In the case of beef, high-quality and low-quality beef are assumed to be fixed proportions (λ and 1-λ, respectively) of cattle demand converted into retail equivalent based on slaughter and technical conversion factors; thus carcass markets are not directly modeled. This is clearly a compromise, since beef supply should ideally be a function of own and input prices. However, modeling limitations currently prevent reconciling a flexible beef supply specification with the restriction that total beef supply be equal to livestock demand converted to retail beef equivalent.[12] As a result, the price effects resulting from a shock to meat markets will overstate the "true" effects. Meat demand (D^m in equation 9) is modeled as a function of own consumer price, the consumer price of substitutes, and income per capita (YPC).

$$\begin{aligned} S^{pork}_{t,r} &\equiv S^{pork}_{t,r}(S^{pork}_{t-1,r}, pp^{pork}_{t,r}, pc^{corn}_{t,r}, pc^{soy}_{t,r}) \\ S^{lamb}_{t,r} &\equiv S^{lamb}_{t,r}(S^{lamb}_{t-1,r}, pp^{lamb}_{t,r}) \\ S^{HQbeef}_{t,r} &\equiv \lambda D^{sl}_{t,r}, S^{LQbeef}_{t,r} \equiv (1-\lambda) D^{sl}_{t,r} \end{aligned} \quad (8)$$

$$D^{m}_{t,r} \equiv D^{m}_{t,r}(pc^{HQ}_{t,r}, pc^{LQ}_{t,r}, pc^{pork}_{t,r}, pc^{lamb}_{t,r}, YPC_{t,r}), m \in \{pork, lamb, HQbeef, LQbeef\} \quad (9)$$

[12] The issue in question is as follows. Ideally, there must be balance between livestock demand (converted to retail equivalent) and total retail beef supply, given that retail beef supply derives directly from livestock demand. The problem is that any such explicit restriction conflicts with the MCP formulation of the model (i.e., the system is no longer square). The solution is to define some appropriate complementary variable to match this restriction, but this definition has not been adequately tested to date. As a result, a fixed, Leontief approach is utilized, with further research aimed at resolving this problem.

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 commercial margins (*MARGD*, reflecting markups from wholesale to retail) 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 (*pc*) must be less than or equal to the import price (*pm*) plus transportation costs and import margins (*MARGM*, reflecting the markup from the port to retail), while the export price (*px*) should be less than or equal to the producer price (*pp*) plus transport costs and export margins (*MARGX*, reflecting the markup from the farm to the port). If either equation is binding, there will be entry of (respectively) imports and exports into the system, viz.:

$$pp^g_{t,r} + TC^g_{t,r,rr} + MARGD^g_{t,r} \geq pc^g_{t,rr} \tag{10}$$

$$pc^g_{t,r} \leq pm^g_t + TC^g_{t,r} + MARGM^g_{t,r} \tag{11}$$

$$px^g_t \leq pp^g_{t,r} + TC^g_{t,r} + MARGX^g_{t,r} \tag{12}$$

Inflows and outflows of commodities across regions are regulated by equations 13 and 14. 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:

$$\sum_{rr} TQ^g_{t,rr,r} + I^g_{t,r} \geq D^g_{t,r} \tag{13}$$

$$S^g_{t,r} \geq \sum_{rr} TQ^g_{t,r,rr} + X^g_{t,r} \tag{14}$$

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:

$$YPC_{t,r} = NFYPC_{t,r} + (\sum_m pp^m_{t,r} S^m_{t,r} + pp^{sl}_{t,r} S^{sl}_{t,r} + \sum_c pp^c_{t,r} S^c_{t,r} - pc^{sl}_{t,r} D^{sl}_t - \sum_c pc^c_{t,r} D^c_{t,r}) / POP$$
$$m \in \{pork, lamb, HQbeef, LQbeef\}; c \in \{corn, soybeans\} \tag{15}$$

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 used to construct regional databases in many instances. Baseline data on production for livestock and crops were 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 some cases to compute average carcass weight and slaughter (Paraguay) and to obtain information on pork and lamb production (Uruguay and Paraguay). Animal demographic data was used to compute the average number of herds and per-km herd density in each region for the epidemiological model.

Data on epidemiological parameters were derived from a number of sources. Detailed, unpublished daily data on the 2000-2001 FMD outbreak in Argentina was obtained from the National Animal Health and Agrifood Quality Service (SENASA) of Argentina and used to calculate the intra-regional dissemination rates of disease used in the model. Weekly outbreak information was available for Uruguay, while no data was known for Paraguay and thus data from Northern Argentina was used to proxy disease spread in Paraguay. Two sets of intra-regional DRs were used: one rate to simulate the spread of disease before the first few clinical cases and a lower rate that reflects the impact of disease control efforts. While the outbreak data provides information on the spread of the disease within a region, it does not assess inter-regional trade. Inter-regional DRs are thus calculated by taking the total regional DR as calculated from the data and subdividing it into intra-regional and inter-regional components on the basis of approximate animal movements between regions.[13] As with intra-regional DRs, two sets of inter-regional DRs were used; after discovery of disease in a region, they are usually set to zero, but in major regions (e.g., the Pampas), they are assumed to be small and stochastic. Both intra- and inter-regional DRs are assumed to be stochastic and uniformly distributed on a region-specific range. Because trade between regions is stochastic, any given simulation of the model can give results that are small (if no trade occurs) or much larger. The remaining transition probabilities are based on those used by Durand and Mahul (2000). The areas used in the model are larger than those used in the DM model (30-km inner ring, 10-km outer ring) to reflect the extensive livestock systems of the Southern Cone. The size of the inner ring also reflects the size of the control area of the 2000 Artigas outbreak in Uruguay.

For the economic portion of the model, certain statistics, such as prices, were somewhat problematic. In the case of Argentina, monthly time series data are available for the 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, it was assumed that the Patagonia/Cuyo price is 10 percent lower than the Liniers price (used to proxy the Pampas price), while the price in the North was 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.

[13] In some instances, the inter-regional DRs are larger than inter-regional trade would suggest. One should note that disease spread can occur from other pathways, such as cross-regional traffic, airborne spread, and wildlife, which would justify a slightly higher spread rate.

Data on demand and retail prices were of varying quality. For Argentina, detailed information on retail prices by type of beef cut by region was recovered from the 1996/97 Household Survey conducted by INDEC. Using this data and insights from expert analysis, 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 Agriculture, 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).[14]

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); DISCOSEM represents the first variety of model, given its integrative nature.

The simulation analysis proceeds as follows. At time $t = 1$, an outbreak is seeded in Paraguay through the introduction of one herd in the state "Incubation". The location of the outbreak in Paraguay is not particularly important. In the next period, $t = 2$, the disease will spread in Paraguay through the expansion of the two rings as described earlier; the definition of the transition probabilities are such that discovery of a clinical case does not occur until $t = 4$.

[14] Econometric estimates for the elasticities of the model are pending and will be incorporated in the final results (Rich, 2005). 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.

Because the possibility of trade between Paraguay and its two adjoining regions is stochastic, it is possible that at $t = 2$ an outbreak will commence in one or both neighboring regions. In the model, it is assumed that there is a five percent chance in any period that such trade happens. If trade occurs, the disease will spread within these regions and then (in subsequent periods) spread southwards (as well as westwards and eastwards) to adjoining regions. In figure 3, a hypothetical illustration of disease spread with the epidemiological component is provided. In the top frame (t=1), the disease is located in a radial area in Paraguay. In the next period (t=2, or the bottom frame), if there is trade, there will be the spread of disease from Paraguay to the two regions to the south of Paraguay. In addition, the radial area within Paraguay will grow in the next period. Note that the spread of disease from Paraguay to these adjoining regions could also occur with some delay or never occur and thus be isolated to Paraguay.

Once the disease is diagnosed in a region, policymakers can apply one of three mitigation strategies. First, one could apply a stamping out policy, which in this model refers to slaughtering all obviously sick animals (i.e., those in the "Clinical" state) and susceptible animals in potential contact with sick herds.[15] Secondly, a vaccination policy could be applied in which obviously sick animals are culled and all susceptible animals are vaccinated. A third policy is what is termed "preventative vaccination", which represents an abstraction of a pure vaccination policy. In this strategy, once the disease is diagnosed in Paraguay, all regions prophylactically vaccinate their herds beginning in vulnerable areas (e.g., auction yards that receive high volumes of trade) and increasing the scope of vaccination in a radial fashion from these areas.

Six scenarios were run with the epidemiological model based on combinations of the above strategies and are summarized in table 1. Because of the stochastic nature of the dissemination rates, Monte Carlo simulations of the model were conducted by compiling the STELLA model equations into Berkeley MADONNA (version 8 Beta 10) and running 1000 batch runs for each scenario. From these simulations, the average length of outbreak, number of animals culled, and number of animals vaccinated were obtained. In addition, a "large" outbreak of each scenario was simulated by using the mean plus standard deviation of these results for a total of twelve simulations overall.

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[15] In the DM model, this scenario is referred to as the SODC strategy (Stamping Out Direct Contact herds).

The economic component is run over a five-year period and it is assumed that an outbreak occurs in year 2. The epidemiological model provides two major pieces of input into the economic module of DISCOSEM. First, the average number of animals culled is used to define the shock to inventories during the outbreak year; in general, this will be small (less than 1 percent). Second, the average length of outbreak is used to calibrate the amount that exports are disrupted in the outbreak year. It is assumed that year 2 exports are restricted to the previous year's exports times a deflation factor, defined as *1-((# of outbreak weeks+16)/52)*. Following Ekboir (1999), it is assumed that it takes an additional 16 weeks after the outbreak has been contained for international trade to resume. It is also assumed that the number of outbreak weeks is rounded to the next highest (whole) week.

The adjustment of world prices depends on the mitigation strategy pursued. In all cases, there will be a fall in world prices received in the outbreak year (year 2) as certain high-value markets will be closed. A 25 percent drop in the export price is assumed for year 2. In the following year (year 3), more high-value markets are assumed to open and export prices are assumed to recover to 90 percent of their former value. In a vaccination (or preventative vaccination) strategy, FMD-free without vaccination markets (and some FMD-free with vaccination markets) will be closed for at least two years after the last vaccination; this will not be the case in a stamping out policy. Correspondingly, export prices in a vaccination policy will remain at 90 percent of the original price in year 4 and only recover in year 5. In a stamping out policy, world prices are assumed to return to normal in year 4.

Costs for each strategy are determined from the epidemiological model and exogenous per-animal control costs. Indemnity payments for culled animals 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 in 1999).[16] In addition, other costs to animal slaughter (e.g., cleaning and disposal costs) are assumed at $48 per animal based on figures from Schoenbaum and Disney (2003) for a hypothetical U.S. outbreak. Vaccination and administration costs are estimated at 90 cents per animal per year (two vaccinations in the

[16] 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.

outbreak year at 45 cents each) (Rich, 2004). Herds are assumed to be vaccinated in the outbreak year only.

Results

Epidemiological Model

The results from the epidemiological model are summarized in table 2. Stamping out policies, not surprisingly, lead to the largest number of animals being culled. In the “average” outbreak scenario, nearly two and a half times more animals are culled in aggregate under stamping out than in the pure vaccination policy (table 2, (a)). At the same time, the duration of a stamping out policy vis-à-vis a pure vaccination policy is about one-half of a week shorter on average. Curiously, an exception to this is the province of Entre Rios, which has a slightly longer outbreak under stamping out than vaccination. Larger outbreaks increase the difference in the outbreak duration between stamping out and vaccination, with stamping out strategies lasting about 1.5 weeks less than vaccination strategies.

Preventative vaccination strategies lead to markedly shorter outbreaks than either stamping out or pure vaccination. With the exception of Paraguay, which is the epicenter of the outbreak, outbreaks in the “average” scenario have a duration of less than a week (table 2, (b)). Moreover, four regions (Cuyo, Patagonia, Uruguay, and NOA) do not report any outbreaks at all. In the larger scenario, similar results are reported. From an epidemiological standpoint, a preventative vaccination policy is extremely effective in reducing the incidence of disease. One should be cautious in interpreting these results, however, since this type of control strategy is an abstraction that assumes perfect targeting of “sensitive” areas in nearby regions that might be infected from an outbreak in Paraguay. At the same time, it highlights that rapid mobilization of control efforts can have a significant impact on limiting the course of disease.

Combinations of these policies (i.e., distinguishing between strategies in Paraguay and the rest of the Southern Cone) give results that are similar to the pure control strategies. A VAC-SO policy in which Paraguay vaccinates while the rest of the Southern Cone adopts the SO strategy leads to slightly shorter outbreaks (with the exception of Paraguay) than a universal stamping out strategy. Fewer animals are also culled. This implies that there may be regional benefits to differential control strategies across the Southern Cone and suggests that coordination of control strategies across borders could lead to greater success in reducing the impact of an FMD outbreak.

Economic Model

The results from the economic model are summarized in tables 3 through 5. In the short-run, a preventative vaccination program is the optimal strategy from the standpoint of the net revenue generated from such an approach (table 3). In addition to being less costly than other mitigations, a preventative vaccination policy causes fewer dislocations to exports, given that under preventative vaccination an outbreak lasts, on average, about 2-3 weeks less than in other control strategies. As a result, the volume (and thus value) of exports is greater in the year of the outbreak under a preventative vaccination policy.

In the long-run, the benefits to both types of vaccination policies are reduced, ostensibly due to greater disruptions to exports over time vis-à-vis stamping out strategies (table 4). The earlier access to high-value export markets engendered by stamping out policies in later years (i.e., gaining access to high-value markets in year 4 rather than year 5) translates into a net present value over a five-year period that is $400-600 million higher than either pure or preventative vaccination policies (table 4). Interestingly, the VAC-SO strategy in which Paraguay vaccinates and the rest of the Southern Cone stamps out has the highest net present value -- in the “average” scenario, the difference in net present value is roughly $15 million. Moreover, all regions, including Paraguay, benefit from such a strategy (table 5). The intuition behind these results is that a VAC-SO strategy is slightly shorter in Uruguay (thus disrupting exports less than SO) and slightly less costly (due to fewer animals being culled) and thus has lower price impacts in the outbreak year than the SO policy. Since Paraguay is not an exporter outside the Southern Cone, the effects of it vaccinating (and thus not having access to high-value markets for an extra year) are muted. In addition, slightly higher prices under VAC-SO in the rest of the Southern Cone buoy prices for products exported by Paraguay within in the Southern Cone.

By contrast, in the “large” scenario, while the VAC-SO strategy has a higher net present value than SO, the regional impacts of such a strategy are mixed (table 5). In particular, the North and

Uruguay are better off under a SO control policy. Unlike the "average" scenario, the duration of an outbreak under the "large" scenario in the VAC-SO strategy is similar to that of the SO strategy (due to the rounding of the outbreak weeks assumed in the deflation factor). Given the interaction in regional trade in cattle and low-quality beef between Uruguay, the North, and the Pampas, the longer duration of the VAC-SO policy in the "large" scenario dampens prices and trade enough in these regions to slightly reduce revenues in the outbreak year.

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.[17] The simulations also consider "perfect" control strategies 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, and Brazil). Indeed, recent outbreaks that occurred in Argentina and Paraguay in 2003 despite vaccination in these two countries demonstrate the fragility of current inter-regional control efforts.

Conclusions

The impacts of disease vary over time and space. The preceding analysis illustrates how animal disease can be examined in a way that captures both temporal and spatial factors in an integrative epidemiological-economic fashion. In the scenarios for FMD control presented above, stamping-out policies were 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 results assume that both vaccination and stamping out could be implemented perfectly and that there are no spillover effects from neighboring or nearby regions. However, as

[17] Indeed, it may be 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.

demonstrated in Rich, *et al.* (forthcoming), regional externalities can play a significant role in explaining the persistence of FMD in South America. The tendency of FMD to spread rapidly over space thus suggests that disease control efforts need to be carried out through a continent-wide approach rather than on a sub-regional basis.

The results of this analysis, while tentative, illustrate a need for sensitivity to the regional diversity of control strategies. 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 and may in fact enhance it. Spatial and dynamic policy analysis can play key roles in determining the types of interventions necessary in such an environment.

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Table 1: Summary of Epidemiological Simulations used in the Model

Disease Control Strategy	**Description**
1) Stamping Out (SO)	All herds that are obviously sick (in state "Clinical") are slaughtered with probability 0.7 or 0.8 depending on the stage of the outbreak. Also, herds in contact with sick herds are slaughtered at rate of α = 2 herds/week in the initial period of disease, α = 5 herds/week in subsequent periods.
2) Stamping Out in Paraguay, Vaccination in Rest of Southern Cone (SO-VAC)	Same as (1) for Paraguay. For rest of Southern Cone, animals are vaccinated upon entry of the disease in a given region by change of probability from state "Susceptible-Exposed" or "Susceptible-Not Exposed" to "Immune". This probability is 0.7 for Argentina, 0.9 for Uruguay (initial probability is zero).
3) Stamping Out in Paraguay, Preventative Vaccination in Rest of Southern Cone (SO-PREV)	Same as (1) for Paraguay. For rest of Southern Cone, animals are vaccinated upon discovery of disease in Paraguay. Transition probabilities are the same as (2).
4) Vaccination in Paraguay, Stamping Out in Rest of Southern Cone (VAC-SO)	For Paraguay, transition probability from state "Susceptible-Exposed" or "Susceptible-Not Exposed" to "Immune" is assumed to be 0.5. Stamping Out in rest of Southern Cone follows description in (1).
5) Preventative Vaccination (PREV)	Same as (3) for rest of Southern Cone. Paraguay naturally follows a standard vaccination policy.
6) Total Vaccination (VAC)	Transition probabilities follow (2) for rest of Southern Cone and (4) for Paraguay.

Table 2: Summary of epidemiological simulations

(a) Average Outbreaks

Region	SO			SO-VAC			SO-PREV		
	Animals Vaccinated	Animals Culled	Duration (weeks)	Animals Vaccinated	Animals Culled	Duration (weeks)	Animals Vaccinated	Animals Culled	Duration (weeks)
Pampas	-	8,639	2.94	396,183	3,633	3.45	1,858,434	163	0.29
Cuyo	-	1,931	2.15	96,522	1,159	2.90	217,414	-	-
Patagonia	-	6,189	2.67	19,131	2,154	3.19	50,458	-	-
Uruguay	-	3,206	2.09	948,198	1,723	2.56	2,815,593	-	-
Paraguay	-	9,363	6.58	-	9,418	6.66	-	9,392	6.62
B. Aires	-	33,985	3.24	638,404	11,931	3.92	3,073,369	436	0.49
NOA	-	1,148	2.12	76,701	699	2.88	156,223	-	-
NEA W.	-	3,575	2.77	350,323	1,999	3.61	1,515,527	151	0.51
NEA E.	-	2,166	2.26	286,639	1,251	2.97	1,096,956	80	0.19
Entre Rios	-	15,046	4.31	551,044	3,685	3.88	2,512,150	116	0.30
TOTAL	**-**	**85,248**		**3,363,143**	**37,652**		**13,296,124**	**10,338**	

Region	VAC-SO			PREV			VAC		
	Animals Vaccinated	Animals Culled	Duration (weeks)	Animals Vaccinated	Animals Culled	Duration (weeks)	Animals Vaccinated	Animals Culled	Duration (weeks)
Pampas	-	8,439	2.87	1,804,727	153	0.28	381,195	3,567	3.37
Cuyo	-	1,885	2.08	210,670	-	-	92,578	1,119	2.77
Patagonia	-	5,877	2.52	48,528	-	-	18,030	2,073	3.07
Uruguay	-	2,995	1.99	2,709,996	-	-	922,357	1,625	2.44
Paraguay	382,390	6,632	10.65	382,409	6,612	10.64	382,402	6,622	10.67
B. Aires	-	32,139	3.15	2,950,620	415	0.44	621,317	12,033	3.83
NOA	-	1,174	2.17	152,853	-	-	69,919	653	2.73
NEA W.	-	3,607	2.83	1,462,890	162	0.56	333,719	1,891	3.40
NEA E.	-	2,164	2.25	1,058,521	70	0.17	271,882	1,223	2.89
Entre Rios	-	14,091	4.20	2,451,317	115	0.29	543,007	3,562	3.76
TOTAL	**382,390**	**79,004**		**13,232,530**	**7,527**		**3,636,406**	**34,369**	

(b) Large Outbreaks (Average plus Standard Deviation)

Region	SO			SO-VAC			SO-PREV		
	Animals Vaccinated	Animals Culled	Duration (weeks)	Animals Vaccinated	Animals Culled	Duration (weeks)	Animals Vaccinated	Animals Culled	Duration (weeks)
Pampas	-	21,591	7.23	997,172	9,274	8.61	4,416,552	432	0.74
Cuyo	-	4,926	5.43	248,553	2,987	7.37	517,178	-	-
Patagonia	-	16,281	6.88	50,897	5,750	8.38	120,535	-	-
Uruguay	-	8,485	5.44	2,536,771	4,630	6.76	6,687,413	-	-
Paraguay	-	10,526	7.74	-	10,624	7.84	-	10,614	7.78
B. Aires	-	86,520	7.96	1,595,690	30,829	9.78	7,310,277	1,123	1.36
NOA	-	2,923	5.34	201,602	1,795	7.29	373,115	-	-
NEA W.	-	8,611	6.52	885,262	4,881	8.64	3,619,837	411	1.51
NEA E.	-	5,450	5.63	793,074	3,200	7.51	2,612,786	244	0.59
Entre Rios	-	38,476	10.63	1,377,877	9,545	9.67	5,965,065	299	0.76
TOTAL	**-**	**203,789**		**8,686,899**	**83,514**		**31,622,759**	**13,123**	

Region	VAC-SO			PREV			VAC		
	Animals Vaccinated	Animals Culled	Duration (weeks)	Animals Vaccinated	Animals Culled	Duration (weeks)	Animals Vaccinated	Animals Culled	Duration (weeks)
Pampas	-	21,136	7.07	4,334,766	412	0.72	971,495	9,214	8.51
Cuyo	-	4,822	5.28	506,348	-	-	243,115	2,944	7.18
Patagonia	-	15,770	6.67	117,916	-	-	48,578	5,620	8.19
Uruguay	-	8,062	5.28	6,534,518	-	-	2,509,720	4,447	6.57
Paraguay	383,099	7,126	11.13	382,975	7,081	11.12	382,752	7,103	11.14
B. Aires	-	82,137	7.76	7,117,819	1,077	1.26	1,573,005	31,500	9.69
NOA	-	2,985	5.46	368,920	-	-	188,023	1,722	7.07
NEA W.	-	8,608	6.59	3,534,453	445	1.70	859,750	4,749	8.39
NEA E.	-	5,468	5.64	2,548,476	224	0.55	767,102	3,161	7.38
Entre Rios	-	36,213	10.39	5,884,788	298	0.74	1,375,283	9,297	9.50
TOTAL	**383,099**	**192,329**		**31,330,980**	**9,537**		**8,918,822**	**79,756**	**8.51**

Source: Model Simulations

Table 3: Short-run impacts of alternative disease strategies in the Southern Cone

	Average Outbreak			Large Outbreak		
Strategy	**Gross Revenue (million USD)**	**Costs (million USD)**	**Net Revenue (million USD)**	**Gross Revenue (million USD)**	**Costs (million USD)**	**Net Revenue (million USD)**
SO	2,488	28.6	2,460	2,165	68.3	2,097
SO-VAC	2,536	15.6	2,520	2,189	35.8	2,154
SO-PREV	2,740	15.4	2,724	2,686	32.9	2,653
VAC-SO	2,504	26.8	2,477	2,164	64.8	2,100
PREV	2,740	14.4	2,725	2,686	31.4	2,655
VAC	2,536	14.8	2,521	2,189	34.7	2,154

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

Table 4: Long-run impacts of alternative disease strategies in the Southern Cone

	Average Outbreak			Large Outbreak		
Strategy	**PV of Gross Revenue (million USD)**	**PV of Costs (million USD)**	**PV of Net Revenue (million USD)**	**PV of Gross Revenue (million USD)**	**PV of Costs (million USD)**	**PV of Net Revenue (million USD)**
SO	19,749	27.2	19,722	19,477	65.0	19,412
SO-VAC	19,161	14.9	19,146	18,873	34.1	18,839
SO-PREV	19,332	14.7	19,317	19,287	31.3	19,256
VAC-SO	19,762	25.5	19,737	19,477	61.7	19,416
PREV	19,332	13.7	19,318	19,287	29.9	19,257
VAC	19,161	14.1	19,146	18,873	33.1	18,840

Source: Model simulations; totals may not add up due to rounding. PV = Present Value.

Table 5: Regional differences between VAC-SO and SO strategies

	Average Outbreak			Large Outbreak		
Region	**VAC-SO Net Benefit (million USD)**	**SO Net Benefit (million USD)**	**Difference (million USD)**	**VAC-SO Net Benefit (million USD)**	**SO Net Benefit (million USD)**	**Difference (million USD)**
Patacuyo	585	584	0.52	571	571	0.20
Pampas	13,145	13,137	7.08	12,906	12,903	3.11
North	2,206	2,205	1.05	2,178	2,178	(0.45)
Uruguay	3,028	3,024	4.96	3,000	3,000	(0.02)
Paraguay	773	772	1.20	760	760	0.71

Source: Model Simulations; totals may not add up due to rounding. The three regions for Argentina above are aggregates of the epidemiological regions (table 2) and are defined as follows:
Patacuyo: Patagonia and Cuyo
Pampas: Pampas, Entre Rios, Buenos Aires
North: NOA, NEA West, NEA East

Figure 1
STELLA representation of the epidemiological component of DISCOSEM

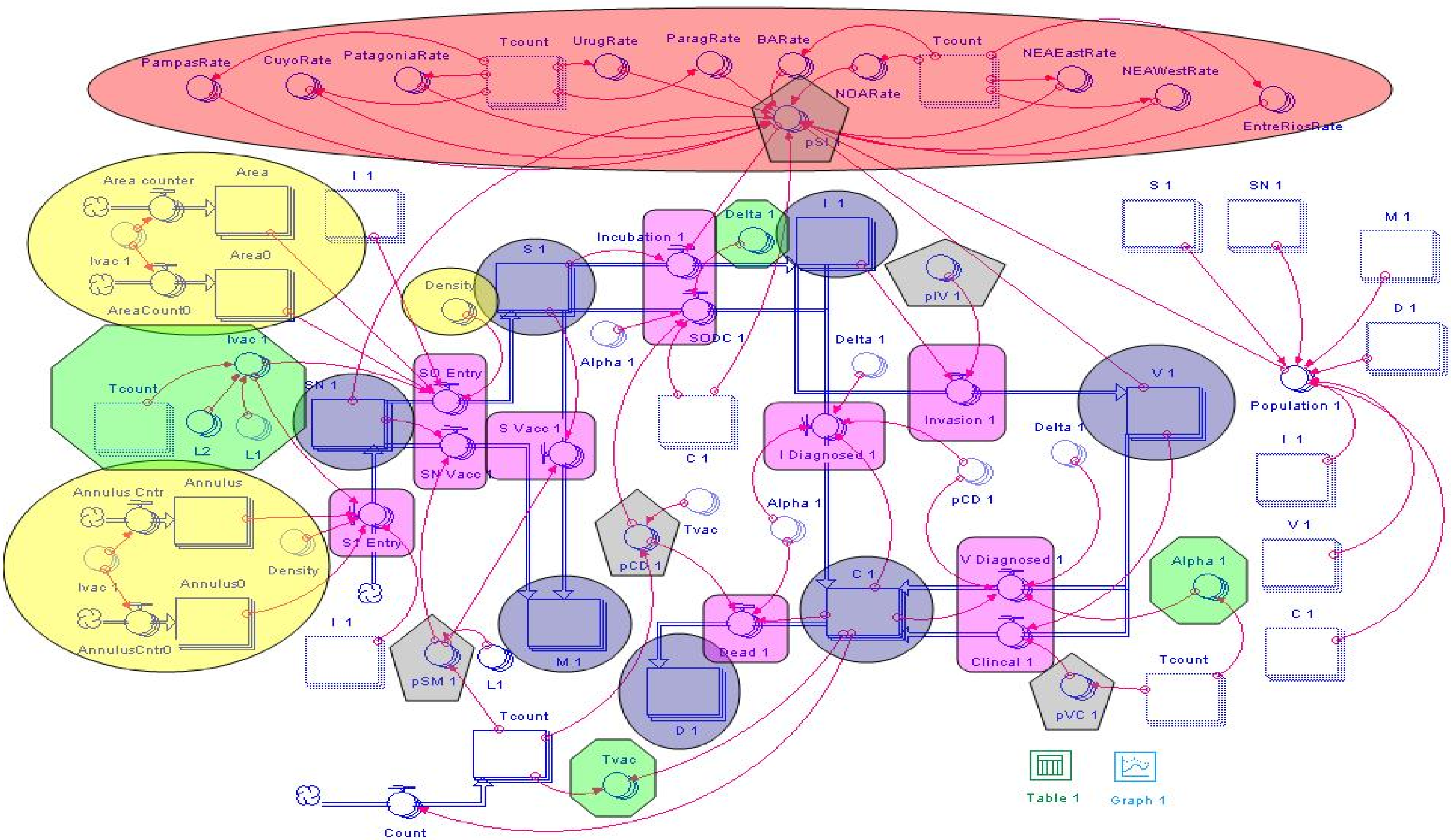

Figure 2
Multi-market diagram of economic component of DISCOSEM

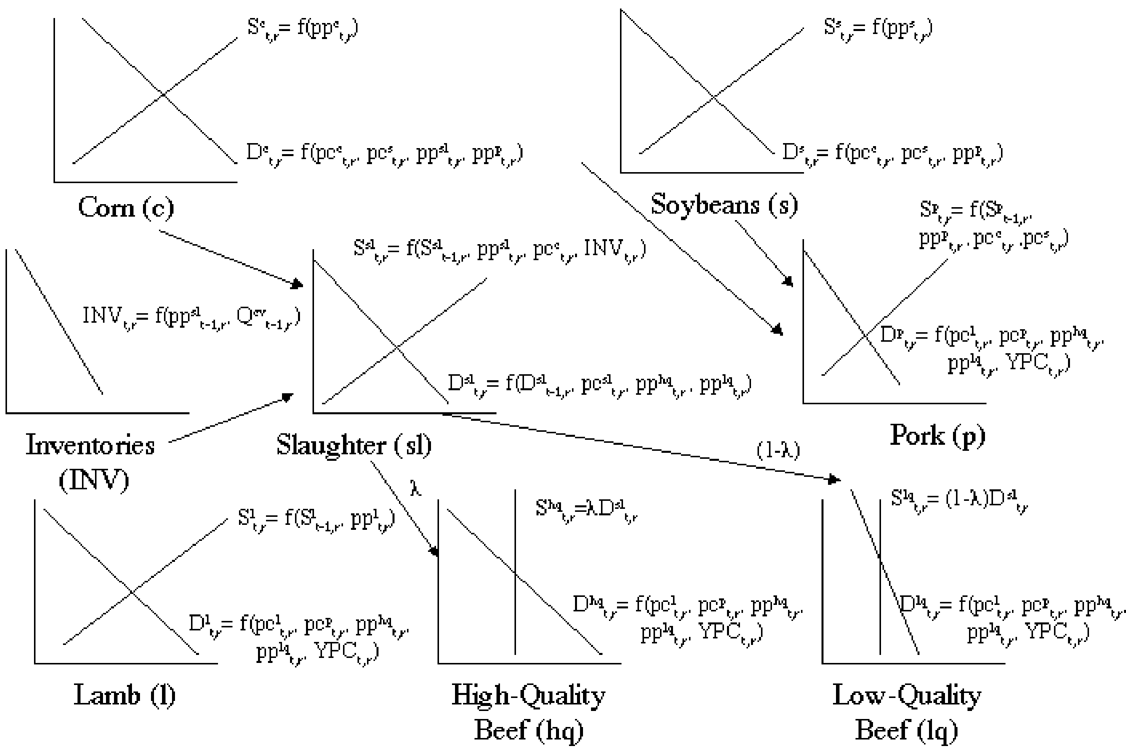

Figure 3
Illustration of hypothetical outbreak with DISCOSEM
(top frame, *t*=1; bottom frame, *t*=2)