An analytical framework for integrated animal disease impact assessment: applications to FMD in the Greater Mekong Sub-Region

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Introduction

Foot and mouth disease (FMD) is a persistent threat to livestock across the Greater Mekong Sub-Region. The disease is considered endemic to the region, and outbreaks continue despite concerted efforts by national governments and international agencies to control the spread of the disease through a variety of measures. Control measures could include prohibition of certain production practices and/or of raising particular species, but these may be important for sources of income for a large number of poor rural farming households. Measures put in place to control FMD may consequently have larger impacts on the lives of the rural poor than FMD itself. To target disease risk management policies in ways that are socially efficient, i.e. reconcile public health and livelihoods objectives requires support by rigorous quantitative assessment methods. This project is intended to provide such decision support to GMS livestock policy institutions, in the context of FMD and other high impact animal diseases.

Devising evidence-based responses to animal and human health risks that balance the interests of a wide variety of national and international stakeholders requires thorough analysis of epidemiological and economic information (past and present), development of scenarios of disease incidence, their likelihood of occurrence, the identification of critical control points and interventions, the costs and impacts of the latter, and, finally, negotiation between stakeholders at different levels, local, national, and regional/international.

This document describes an approach to systematically address the recurring need of national governments and the international community to respond to high impact disease threats using the incursion of FMD into the Greater Mekong Sub-Region, including Myanmar, Vietnam, Cambodia, and Lao PDR as cases from which to derive broader lessons. We first develop a conceptual framework to assess the multi-dimensional impacts of animal diseases, based on the characteristics and determinants of diseases and their impacts at different levels. We then focus on the measurement of impacts along the value chain and subsequently turn to methods for evaluating economywide impacts, both areas, where applications in the GMS have been limited. Value chain analysis offers detailed assessment of the directly affected livestock sub-sector itself, decomposing it from farm to consumer dining table and detailing the economic consequences of animal disease risk and its management. The economywide assessment looks across the entire economy at how disease risk affects the overall livestock sector, allied production and market activities, as well as consumers and stakeholders indirectly linked via spillover effects from outbreaks and policy responses. Taken together, supply chain and economywide assessment offer governments a comprehensive overview of the potential costs of high impact animal disease risk, as well as the benefits of effective risk management and outbreak response policies.

Because they rely on different data, methods, and expertise, the two components of risk and response assessment capacity will be covered separately. This overview summarizes the two perspectives generally, including a review of general data requirements and expected outputs of the two approaches. In addition to this, detailed training modules for each approach are being developed in a suite of knowledge products.

Economywide Perspectives on High Impact Animal Diseases

A typology of disease-related impacts

Animal diseases affect livestock and human populations alike. At a crude level, we can categorize animal diseases generally on the basis of (i) their persistence or emergence in animal populations and (ii) their impacts on public health. Table 1 provides a simple means in which different diseases can be clustered based on their animal and human dimensions.

Table 1: A simple typology of animal diseases

		Type of animal disease	
		Chronic/endemic	Epidemic
Human populations affected	No	(a) Helminthiasis, mycoplasmoses	(b) FMD, classical swine fever, African swine fever, PRRS
	Yes	(c) Zoonoses and food-borne diseases (e.g. brucellosis, rabies salmonellosis)	(d) Avian Influenzas (e.g. HPAI H5N1, H7N9)

While this classification is useful in distinguishing different types of animal diseases, their economic impacts can vary markedly. Generally speaking, as we progress from endemic to epidemic diseases (e.g., (a) and (c) to (b) and (d)), there will be greater spillovers (externalities in economic parlance) across sectors and borders. FMD, for example, has considerable impacts on local and international trade alike, with multifaceted effects on other sectors such as crops that use livestock as an input to production. By contrast, diseases in (a) in table 1 have less in the way of international impacts, but may still have important local impacts as well as externalities on the environment (e.g. the impacts of acaracides for tick-based disease on groundwater stocks).

While the framework in table 1 is a useful starting point, it is instructive to unpack the various dimensions underlying an animal disease incursion. Rich and Perry (2011) identify five aspects (or determinants) of disease impact based on the characteristics of the disease and its setting that are useful to motivate our discussion: (i) disease characteristics, (ii) production systems characteristics, (iii) market characteristics, (iv) livelihoods characteristics, (v) and control characteristics.

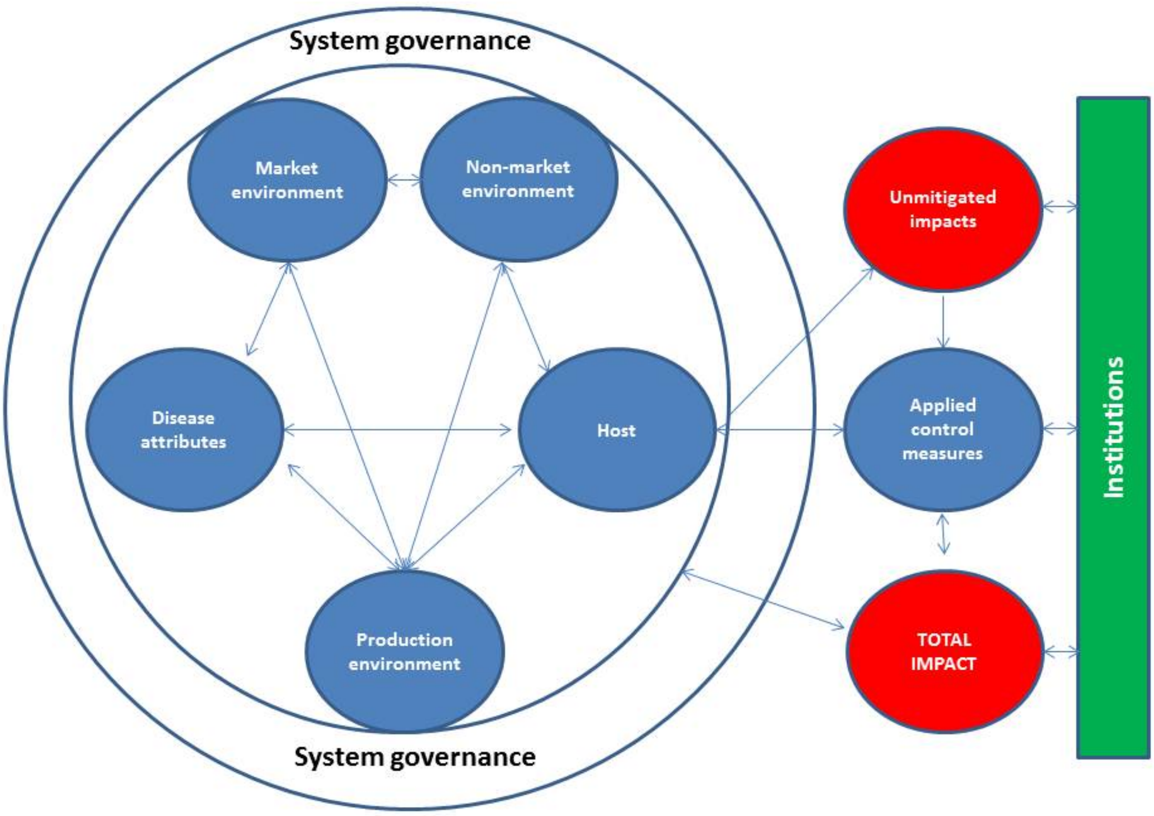
- **Disease characteristics** refer to the epidemiology of the disease and its biological impacts in terms of severity, spread, incidence and host range. FMD, for instance, has minimal impacts on animal mortality and is not a zoonotic disease. Nonetheless, FMD is highly contagious and spreads over long distances in short periods of time due to animal, and its impacts on animal morbidity and productivity can be wide-ranging. By contrast, a disease such as HPAI, while also fast-spreading, has causes significant mortality in chicken and other poultry species and can have a high case fatality rate in humans. Indirectly, disease-related impacts influence flock / herd demographics and incentives in the livestock sector. Diseases such as rinderpest, for example, force producers to behave more defensively in terms of their herd composition (e.g., holding older, less vulnerable animals). In such cases, risk management trumps productive efficiency in the calculus of stakeholders.

- **Production systems characteristics** refer to the relationship between production systems and disease impacts. For example, some diseases (such as HPAI or African Swine Fever) are more likely to cause severe losses in intensive systems, with implications on the types of producers affected. In addition, the degree to which production systems interact through market or non-market means will also be important in determining spread and thus impact, as will the extent that products and by-products (e.g., milk, manure, and draught labor) are generated. Dynamics also matter greatly, both in terms of duration, their interface on production cycles, and impacts on livestock seasonality (i.e., when a disease occurs). Rich and Wanyoike (2010) found that the 2006/2007 RVF outbreak in Kenya had larger impacts on producers as the disease struck at a peak sales time. The interactions between livestock and other sectors will also comprise a type of production impact. For instance, rinderpest and FMD both have important impacts on crop sectors that rely on draught labor for production.
- **Market impacts** of an animal disease depend on the types of markets accessed by different livestock producers. Formal and informal sectors face impacts from animal disease that might differ markedly. Commercialized producers face direct impacts from the closure of formal markets, for example, while backyard producers might lose crucial petty income derived from livestock needed for school fees. Market impacts concern not just producers but other downstream actors in the value chain, including traders, processors, and service activities associated with livestock production, processing, and trade (Otte et al., 2008; Rich et al. 2009). The degree to which the agricultural sector influences non-agricultural activities will also be an important market impact. For instance, one of the major potential impacts of HPAI in Thailand was its consequences on the tourism sector (McLeod and Rushton 2007).
- **Livelihoods impacts** can be both market and non-market in nature. For commercialized producers, the loss of animals from a disease outbreak or inability to sell animals due to market closures can negatively impact livelihoods when such production represents the predominant source of income. Livelihoods impacts have gender and non-market impacts as well, particularly in settings where livestock will perform an important social or cultural role that could impede successful control efforts. This was a significant complicating factor in Indonesia with HPAI, where poultry have both market and cultural significance in society.
- **Control strategies** further influence the impact of a disease. Both control and risk management strategies (vaccination, surveillance, stamping out, etc.) all result in some degree expenditure that is borne by the public sector, private sector, or a combination. The degree to which private or

public stakeholders invest in disease risk and impact mitigations can further influence the frequency and severity of a disease incursion.

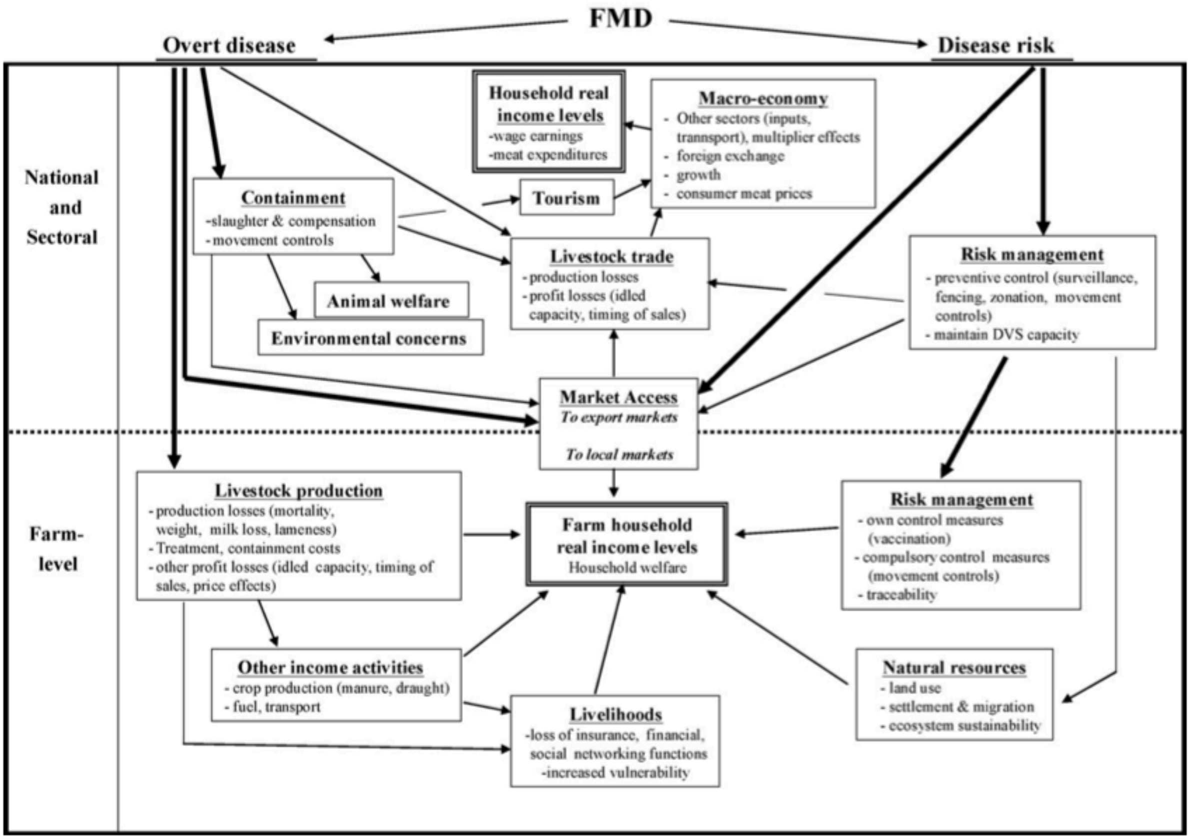
We can distill this framework more explicitly as illustrated in figure 1. Here, we establish the relationships and interactions between the types of disease (disease agent), hosts impacted, and the environments that influence (and are influenced by) these. The totality of these relationships are modulated by the governance of the livestock systems in question, specifically the relationships, conventions, and rules that define transactions and stakeholder behavior in these systems. Governance is often overlooked as a mitigating factor, but is crucial in how it contextualizes livestock systems. On the right side of figure 1 are measures taken by stakeholders to control disease (applied control measures) that are influenced by unmitigated impacts, including risk management decisions taken by stakeholders (cf. figure 2 below), as well as the environmental and disease impacts on the left side of the figure. Combined, these provide us with a totality of disease-related impacts.

Figure 1: Interactions among dimensions of animal disease impacts



Although the effects of diseases like FMD initially become evident in domestic livestock, disease outbreaks have repercussions that go far beyond primary producers. These repercussions are to a large extent a result of public and private responses to the (real or perceived) **risk** of the disease and its **potential** effects rather than to the actual, direct on-farm impacts. Thus, any policy responses and control measures need to take into account this plurality of stakeholder reactions and interests as well as their potential to contribute and their incentives to undermine both risk management and outbreak response programs.

Figure 2: Economywide impacts of FMD

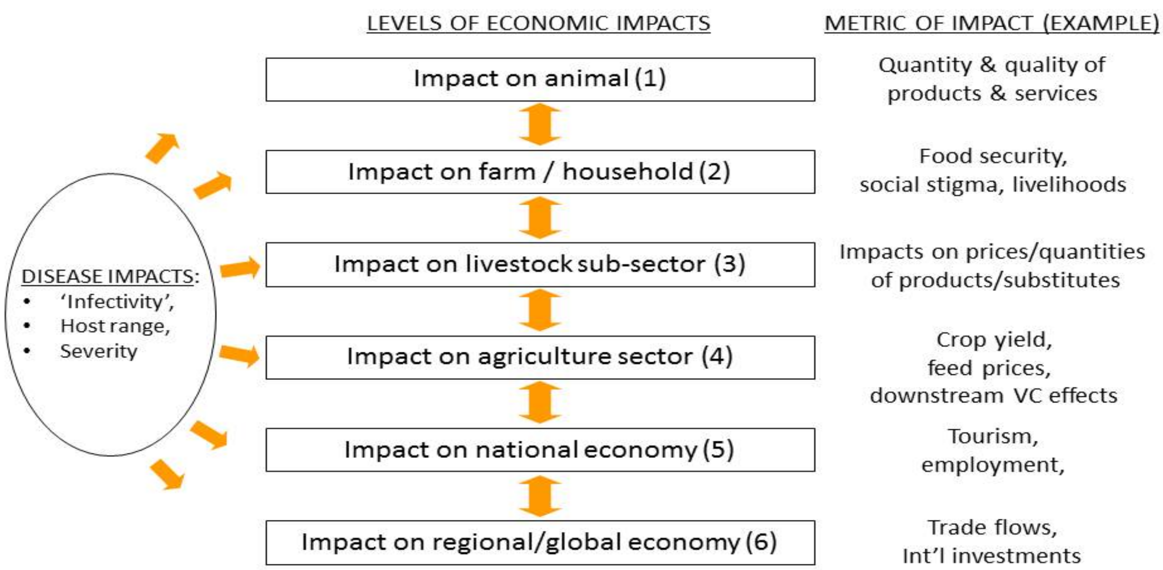


Source: Adapted from Perry and Randolph, 2003.

As Figure 2 makes clear, the economic ramifications of significant animal disease outbreaks can extend far beyond the animal production systems themselves. Even when no generalized human contagion emerges, supply chain linkages propagate shocks from the afflicted animal sector up and down agro-food supply chains and across the consumer sectors associated with rural producers and urban consumers. In the event that risk aversion induces spillovers to other economic activities (tourism, health services, trade and transport, etc.), the indirect effects of disease outbreaks can far outweigh direct ones.

We can overlay these dimensions of disease impacts with the different types and magnitudes of impacts animal disease have at farm, local, regional, national, and international levels. Following Rich, Roland-Holst, and Otte (2012), we can identify six different levels of aggregation: (1) household or farm level impacts, which can include non-farm related livelihoods impacts; (2) cattle sector impacts; (3) general livestock sector impacts, including substitution impacts at production and consumption levels; (4) national-level value chain impacts based on the forward and backward linkages of livestock with other sectors of the economy, particularly agriculture; (5) downstream national level impacts in non-agricultural sectors such as tourism, as well as other externalities such as effects on the environment, wildlife, and (for zoonotic diseases) human health; and (6) impacts at the global or sub-regional level due to international trade bans, for instance. Figure 3 below provides an illustration of the interactions of disease characteristics and economic impacts, while table 2 provides an application of the overlay of disease characteristics with their impacts at different levels of analysis. The example given is for rinderpest (following Rich, Roland-Holst, and Otte 2012), but can be easily adapted for any number of animal diseases of interest.

Figure 3: Interactions of disease characteristics and levels of economic impact



In section 3, we will review a subset of economic tools that can be used for animal disease impact, focusing our discussion primarily on impacts at levels 4-6, where there is often a dearth of analysis. These tools include value chain assessments and economywide models such as SAMs and CGE models. Tools for levels 1-3 have been summarized in past reviews on animal disease (see, for example, Rich et al. (2005)) and include simple forms of benefit-cost analysis, linear programming models of farm management, and partial equilibrium models.

Table 2: The impacts of animal diseases based on different dimensions and characteristics of epidemiological and economic impact: an application to rinderpest

Dimension of impact	**Disease characteristics by level of analysis**					
	Level 1: Farm	***Level 2: Cattle sector***	***Level 3: Livestock sector***	***Level 4: Agricultural/ Value-chain***	***Level 5: National***	***Level 6: Global***
Disease characteristics						
Severity of disease	High mortality in cattle – strong livelihood impacts in pastoral settings	High mortality impacts: production systems oriented at risk management rather than productivity		Trade bans further accentuated mortality effects	Intensity fuelled by animal movements	Strong externality impacts across borders
Frequency	Endemic, pre-campaign; sporadic post-campaign					
Mode of transmission	Primarily through animal contacts (local, regional, global)					
Spatial spread	Transboundary fuelled by pastoral movements (local, regional, and global)					
Public health	None					
Production characteristics						
Production system	Generally extensive, pastoral (particularly in Africa)	Predominance of traditional, informal markets, loose value chain linkages			Transboundary movements important	
Production cycle	Long production cycles					
Population size	Variable population sizes					Impact depends on net import/export status
Importance of by-products	High, particularly in terms of meat, milk, hides, manure, and animal traction					
Market characteristics						
Level of commercialization and market integration	Smallholder and commercial sectors both affected; large impacts in pastoral settings and domestic markets			Market access impacted for smallholder and commercial sectors		Informal marketing problematic for transboundary spread
Scope of value chains	Relatively simple, arms-length transactions, with limited value-adding or innovation downstream					
Non-sector impacts				Impacts in agricultural and service sectors based on forward and backward linkages	Potential impacts on wildlife	Impacts in agricultural and service sectors based on importance of trade

Dimension of impact	**Disease characteristics by level of analysis**					
	Level 1: Farm	***Level 2: Cattle sector***	***Level 3: Livestock sector***	***Level 4: Agricultural/ Value-chain***	***Level 5: National***	***Level 6: Global***
Level of socio-economic development	Generally low in affected regions					
Livelihoods characteristics						
Role of livestock in livelihoods	High importance in pastoral settings					
Cultural importance of livestock	High importance in pastoral settings					
Control characteristics						
Effectiveness of current control technologies	Effective, thermostable vaccine exist that confers lifelong immunity					
Resource requirements for control	Costs associated with vaccines, delivery, and laboratories; donor support has been crucial in the past					
Maintenance costs for control	Importance of sero-surveillance in difficult environments; CAHW and participatory epidemiology play key roles					Coordination necessary across borders
Externalities related to disease control			Possible links of rinderpest control to increased incidence of PPR in small ruminants		Environmental consequences on carrying capacity.	
Institutional capacity	Strong international coordination with local partners in successful campaigns					

Source: Rich, Roland-Holst, and Otte (2012)

Priority Stakeholder Groups

As the earlier discussion suggests, high-impact animal diseases can exert pervasive impacts across an economy, with effects that also reverberate over time. In the proposed economywide assessment capacity, we highlight consideration of several leading groups, discussed briefly below.

Producer households

Producer households are key stakeholders. In the context of FMD, animal disease impacts primarily impact producers through animal morbidity, including:

- Productivity losses for dairy animals;
- Higher feeding costs for sick animals;

- Control and treatment costs for sick animals;
- Opportunity costs in labor and time associated with keeping animals longer than normal;
- Animal traction impacts, based on a reduction in income from renting animals for animal traction, or delayed/reduced production on-farm from the use of own animals.

Impacts on animal mortality from FMD are generally lower than morbidity effects and confined to younger animals, though certain species common in the GMS, particularly pigs, are more susceptible to FMD. Other important impacts at the producer level include risk mitigation costs, including steps to manage incursions of FMD such as vaccination or biosecurity protocols, although the former are sometimes paid for by the public sector

The impacts of FMD vary considerably by the type of production system considered. Commercial producers are more impacted by the loss of markets and productivity associated with FMD, in addition to the high costs associated with preventive control. By contrast, the impacts of FMD on smallholder and backyard producers depend on the extent livestock are incorporated in livelihoods. Perry et al. (2002) found the highest impacts at the farm level occurring due to (i) animal traction effects, (ii) commercial pig producers, and (iii) smallholder dairy producers.

Livestock (Cattle and Pig) Industries

Thailand is the world's sixth largest producer of poultry meat. However, the industry is small in comparison to the overall economy, and represents just 0.4% of gross domestic product (GDP)1. In Vietnam, the poultry industry represents 0.6% of GDP[2].

These estimates might suggest that in Viet Nam, for example, if poultry production fell to zero for a period of six months, lost income would amount to 0.3% of the value of GDP. However, this approach ignores the ability of farmers to substitute resources towards other animals or crops, which would mitigate income losses to some degree[3]. Farmers are also diversified into other forms of meat production. During earlier outbreaks, for example, pork and beef prices significantly offset revenue losses in restricted poultry sales (see below).

Although FMD threatens the livestock industry in affected countries, the burden appears to be skewed towards small to intermediate market-oriented producers and consumers. In many countries, big agribusinesses appear better positioned to limit risk and take advantage of government assistance[4].

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[1] Castillo and Verbiest 2004:2
[2] World Bank 2004:1
[3] World Bank 2004:1
[4] Delforge

Other Agriculture Industries

FMD has a sharply negative impact on the demand for poultry products. However, as consumers substitute away from poultry, this increases the demand for other foods, particularly meats such as pork, beef and mutton.

For example, in response to sporadic FMD outbreaks, substitution away from chicken towards pork has been a boon for Vietnam's hog industry, where pork prices rose 15% from 2004 to 2005. During 2004, the industry increased production from 25 million heads to 26 million, and a similar increase is expected for 2005[5].

Industries related to substitute products also stand to benefit, for instance, the hog industry in Vietnam accounts for 60% of total commercial feed demand, and industry expansion may lead to an increase in feed production of around 10%[6].

FMD can further have impacts throughout the livestock value chain as well as in other related agricultural sectors. Movement bans (domestic and/or international), for example, impact a range of downstream actors in the livestock value chain, including traders, processors, butchers, retailers, and exporters, as well as other ancillary service providers in formal and informal markets that serve the livestock sector. As noted by Perry et al. (2002), FMD in the GMS can also impact the agricultural sector through its effects on animal traction, reducing agricultural productivity and/or delaying planting.

Consumer Households

Animal disease impacts households directly, in terms of real and potential health risk, and it also affects consumption patterns. Buying habits usually respond quickly and adversely to perceived food risk, and may be slow to re-adjust as real risks decline. In addition to demand shifts toward substitute animal products, consumers may also extensive indirect effects through the price system, as the economy adapts to the disease shock. (Export bans may benefit consumers as domestic prices drop, though this depends on whether domestic demand falls as well)

Broader National Economy

FMD control measures can have sharp impacts in the tourism sector, as witnessed in the UK during the 2001 FMD outbreak whereby strict movement controls reduced tourism numbers (Rich and Winter-Nelson 2007). In the GMS, the tourism industry account for roughly 6% of GDP[7]. Tourism and related industries, such as airline and hospitality industries, are extremely vulnerable

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[5] Reuters
[6] Reuters
[7] Cezayirli 2005:1, Reuters

to negative shocks in public sentiment because of the elastic nature of demand. All countries in the region now rely heavily on international tourists, who can easily switch destinations or postpone their holiday in response to any kind of adverse event.

Any negative shock to one sector of the economy can have extensive secondary effects. For example, layoffs in the livestock or tourism industries result in less spending, which in turn weakens GDP growth. The degree to which the entire economy is affected by a FMD outbreak depends upon the scope of the outbreak itself and the ensuing national and international responses, including spill-overs to trade and other agrifood sectors.

In some ways, the 1997 Asian financial crisis has left Asian financial markets better prepared for the shocks like FMD and other high impact animal diseases. Investors are much better informed about the risks they face and the returns they should realistically expect.

From an economic perspective, Asian governments and central banks are now in a stronger position to deal with a crisis of confidence that might hit financial markets as, among other adjustments, many Asian central banks currently have massive foreign reserves. For instance, GMS have the highest reserves in their collective history[8].

Having said this, shocks to a major export sector like livestock could have serious transitory impacts, including financial contagion to other agrifood sectors, declines in foreign direct investment, and even capital flight. Greater policy coordination to avert trade disruption and financial spillovers should be a high priority for the region.

International Community

Disease outbreaks among domestic animals can have repercussions for export markets. In the cases of BSE, SARS, and FMD, countries with significant outbreaks have faced more stringent export standards and some bilateral trade prohibitions. These reactions generally affect large producers and processors, who however have greater means to bridge revenue shortfalls and to invest in restocking and more stringent SPS standards, but the short-term effects can still be very adverse.

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[8] CIA Factbook

Assessment Tools and Methodologies for Impact Assessment

To support more effective, evidence-based animal disease risk assessment and policy response, we use two primary quantitative tools, economic accounting devices and economic forecasting models. These analytical tools bring together diverse data sources across the supply chain and the economy as a whole and synthesize them in a framework that explicitly captures linkage effects across activities and stakeholder groups.

Supply Chain Perspectives on High Impact Animal Diseases

Animal diseases pose significant threats to livestock sectors throughout the world, both from the standpoint of the economic impacts of the disease itself and the measures taken to mitigate the risk of disease introduction (Perry and Randolph 2003). These impacts are multidimensional and not always well understood, complicating effective policy response. This is particularly the case in much of the developing world, where livestock play an important part in household livelihoods and in some circumstances serve as a pathway out of poverty (Perry and Grace, 2009). In such contexts, where livestock contribute food, income, draught power, an asset base, and various social functions, the impacts of animal disease, and in particular their ramifications on poverty, may be difficult to tease out (Perry and Rich, 2007; Randolph et al., 2007; Perry and Grace, 2009).

Value chain approaches have been applied in the development literature since the late 1990s, culminated in a handbook published by the Institute of Development Studies (IDS) at the University of Sussex (see Kaplinsky and Morris 2001). Other related handbooks (M4P, ValueLinks) have been developed in the past few years that have built upon these methods to assist donors and NGOs to develop pro-poor value chains in agricultural and livestock settings. Value chain methods have not been extensively applied in livestock and livestock disease settings until relatively recently. Humphrey and Napier (2005) provided a generic framework for ways supply chain analysis could be utilized in livestock systems. However, the last three to four years has seen a relative surge in application in the context of animal health emergencies. Kobayashi (2006) illustrated the utility of supply chain analysis in the context of avian influenza control. In her analysis, Kobayashi demonstrated how supply chain mappings could not only highlight the interactions, flows, and governance mechanisms inherent in different poultry sector marketing channels in a visual format, but also how they could identify bottlenecks or critical control points in the chain that may work against effective compliance.

Qualitative Models: Data Requirements and Outputs

As detailed in Kaplinsky and Morris (2001) and summarized in Rushton (2009) and Rich et al. (2011), supply chain analyses focus on initial information and results communication in four main areas:

- **Mapping the supply chain**: describing the actors inherent in all stages of production, distribution, processing, and end-sales, including service providers, and the nature of such interactions qualitatively and quantitatively (e.g., flows and values of products between actors and different chains) (Rushton, 2009); • **Understanding governance in the supply chain**: assessing power relationships in the chain in terms of who coordinates economic activities, standards, and transactions, and the means by which this is done (e.g., *ad hoc* arms-length transactions, relationships, vertical coordination) (Rushton, 2009);

- **Upgrading in the supply chain**: identifying opportunities for improving the position of a particular actor within the chain, through more efficient (or new) processes, development of new products, changing the mix of products and activities within a chain to add value, or moving into new chains altogether;

- **Distributional issues in the supply chain**: highlighting equity considerations in the supply chain, in terms of who benefits from the participation in the chain and various share of value distributed among different chain actors. These can look at different typologies of actors based on household income, gender, or production system.

Typically, the information above is generated by a qualitative supply chain study. In this context, semi-structured interviews are conducted with livestock and crop producers, traders, processors, butchers, retailers, service providers, and institutions (veterinarians, government, etc.) that allow the analyst to assemble maps of the value chain and inform an analysis of the governance structure and upgrading options in the value chain, and the distributional consequences of value chain participation. In the context of animal health, a particular strength of the approach is in its focus on relationships, characteristics, and dynamics that take place among supply chain actors and influence risk. Value chain mappings, for example, help to visualize and locate prospective risk "hot-spots" in the value chain, where greater policy focus is needed. A focus on governance highlights what types of marketing and structures govern transactions in the chain and the extent to which power relationships (e.g., monopoly or monopsony power) or coordination mechanisms influence such dynamics. An analysis of governance might, for example, determine whether transactions between segments of the chain are governed by *ad hoc* arms-length transactions or more formalized types of vertical coordination. This might matter for a couple of reasons. First, where transaction mechanisms are more formalized, the ability of diverse chain actors to coordinate activities in a manner that promotes greater biosecurity efforts or control of disease is potentially enhanced, particularly if regulations and standards are pushed and championed by a key player in the chain. In developed countries, supermarkets often coordinate transactions within the chain to ensure quality specifications are met, which often serve as a source of competitive advantage between retailers (Dolan and Humphrey 2000). In the context of livestock production, a good example of this are the efforts of FAN (Farm Assured Namibian) Meat in Namibia which coordinates public and private efforts at traceability and certification to ensure market access in high-value EU export markets (Perry et al., 2005). Conversely, where market power is concentrated among one segment of the chain, incentives for compliance by other chain actors might be reduced, particularly if such market power distorts appropriate price signals or information received by other actors. Furthermore, where governance mechanisms are loose or informal, or where a mix of supply chains interact, each with its own type of governance system, disease control can be problematic.

Unfortunately, most value chain analysis focuses mechanically on the value chain mapping and visualization of the chain and hotspots, rather than the underlying context and governance structure that influences and causes it, potentially reducing the impact that a thorough value chain assessment could have on understanding the disease and its impact more holistically. Rich and Wanyoike (2010), in the context of RVF in Kenya, and Akinwumi et al. (2011), in the context of HPAI in Nigeria, are notable exceptions in this regard.

From Qualitative to Quantitative Value Chain Studies

An overwhelming majority of value chain analyses are qualitative, which provides little scope for assessing the impact of different intervention options. However, new techniques for quantitative analysis of value chains have been applied over the past couple of years to remedy this deficiency. Rich et al. (2011) proposed the use of system dynamics (SD) tools in livestock settings to model livestock value chains. A SD model is a dynamic model that maps out flows and relationships between actors with which one can examine the impact of alternative scenarios over time, and which can incorporate the various delays present in livestock systems. SD models thus map the *processes* that exist within the value chain, with behavioral and financial parameters that influence these processes endogenized as sub-models or through defined relationships. In doing so, *feedbacks* arising from policies or interventions can be identified to assess the tradeoffs between different policies. Rich (2007) developed a framework in which a simple livestock supply chain was integrated with an epidemiological model of poultry disease, with changes in disease and control strategies affecting value chain dynamics, and vice-versa. Hamza (2012) developed a similar structure in the context of sea lice control in Norwegian salmon. Similarly, Naziri et al. (2012) implemented an SD model of the Namibian cattle value chain in which herd dynamics, FMD risk status, and downstream cattle marketing were integrated to assess the cost-effectiveness of alternative protocols to implement commodity-based trade platforms.

A conceptual framework for applying SD in livestock value chains can be found in figure 5 below, based on Hamza and Rich (2013). In this framework, a SD model of a livestock value chain would comprise of five inter-related modules (or blocks) below. The production block characterizes the process of production, from producer to downstream trade, processing, and retail. The financial block details the benefits and costs associated with production, and influences the choice of different production technologies based on their profitability. The performance block denotes the efficiency of the value chain depending on different metrics such as minimization of inventories or timeliness of sales. The policy block allows the system to be shocked, based on various technical interventions from either public or private bodies. The risk block highlights risks to the value chain that influence production (and thus profitability and performance), and could be modeled, for instance, as an epidemiological model of FMD. In this manner, value chain analysis moves beyond simple mappings of actors towards a simulation tool to understand the influence of alternative public policies affecting the value chain as an entity. The next section will illustrate the implementation of such models in the context of animal health impact assessments.

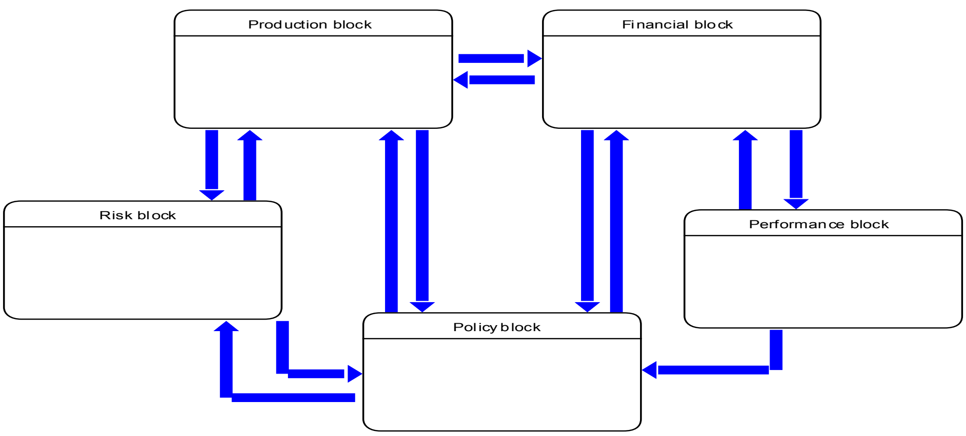


Figure 4: A framework for quantitative value chain analysis in livestock

Source: Adapted from Hamza and Rich (2013)

Implementation of Supply Chain Models in Animal Health Impact Assessments: Integrating Economic and Epidemiological Models[9]

An integrated epidemiological-economic model assesses two types of disease-related impacts. First, animal diseases that impact productivity (e.g., FMD) or cause significant mortality (e.g., avian influenza), and control measures taken to control outbreaks, will influence the stock of animals held by producers. For some diseases, such as FMD or Rift Valley Fever, impacts will be higher among younger animals and on breeding stock, which will affect animal stocks in subsequent periods. Second, animal diseases can have demand impacts, either by reducing domestic demand due to perceived food safety concerns (particularly for zoonotic diseases such as avian influenza or BSE) or international demand through trade bans, or both. In both cases, feedback effects matter, necessitating integrated models that allow closing the feedback loop between disease introduction and actions taken to control (or not control) disease. For instance, a disease outbreak will cause producers to make different decisions on the marketing and holding of animals which in turn will have an impact on the evolution of disease itself. A good example of this is the distress selling of infected birds by smallholders in Indonesia due to avian influenza, which likely amplified the impact of HPAI, particularly over space.

An integrated supply chain model of animal disease thus needs to integrate two specific types of models – an epidemiological model of disease spread and an economic model of animal production and trade. These will be discussed below, with examples utilizing the STELLA modeling language (http://www.iseesystems.com) and drawing from Rich (2007) and Naziri et al. (2012). The latter model was not purely an integrated model in that a specific epidemiological model was not utilized, but it links a simple stochastic incursion of FMD to the system and its influence on prices and market access. However, the richer population structure used in Naziri et al. (2012) and its application to cattle presents itself as a more robust means to model livestock systems in the GMS.

First, the epidemiological component of the integrated model uses a simple state-transition model, in which animals (or herds) are partitioned into different states of nature depending on the evolution of disease over time. The most commonly used model in the S-I-R model, whereby animals can be either susceptible to disease (S), infected (I), or "removed" (R) from the system. Some models distinguish the removed state between animals or herds that are "removed" due to recovery from disease, those that are "immune" due to vaccination, or those that die. The differential equations that characterize the S-I-R model are presented below in equation (1), where S, I, and R are the population states as defined above and the

[9] This section draws from Rich (2007).

parameters β and α represent the transition rates from Susceptible to Infected and Infected to Removed, respectively. In addition, control measures such as vaccination will further modulate the dynamics of the system – in such cases, there will be an additional transition (and equation) between susceptible animals and removed animals that will depend on the rate of vaccination.

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

Figure 6 illustrates these components in a system dynamics framework as modeled in STELLA, using the poultry model in Rich (2007) as an example. In the figure, the boxes represent the *stocks* of animals at time *t* that are in the each of the different states (Susceptible, Infected, or Removed). The arrows between stocks are known as *flows* and highlight the transition of animals between states based on the evolution of disease and the entry (and exit) of animals from the system. The model relaxes the standard S-I-R assumption that the total population in the system is fixed. At each time period, a certain number of animals enter the system as susceptible animals based on the birth of new animals (here, denoted by the parameter "hatching"). If there is no disease, animals remain in the state Susceptible until they are either sold for slaughter or die naturally.

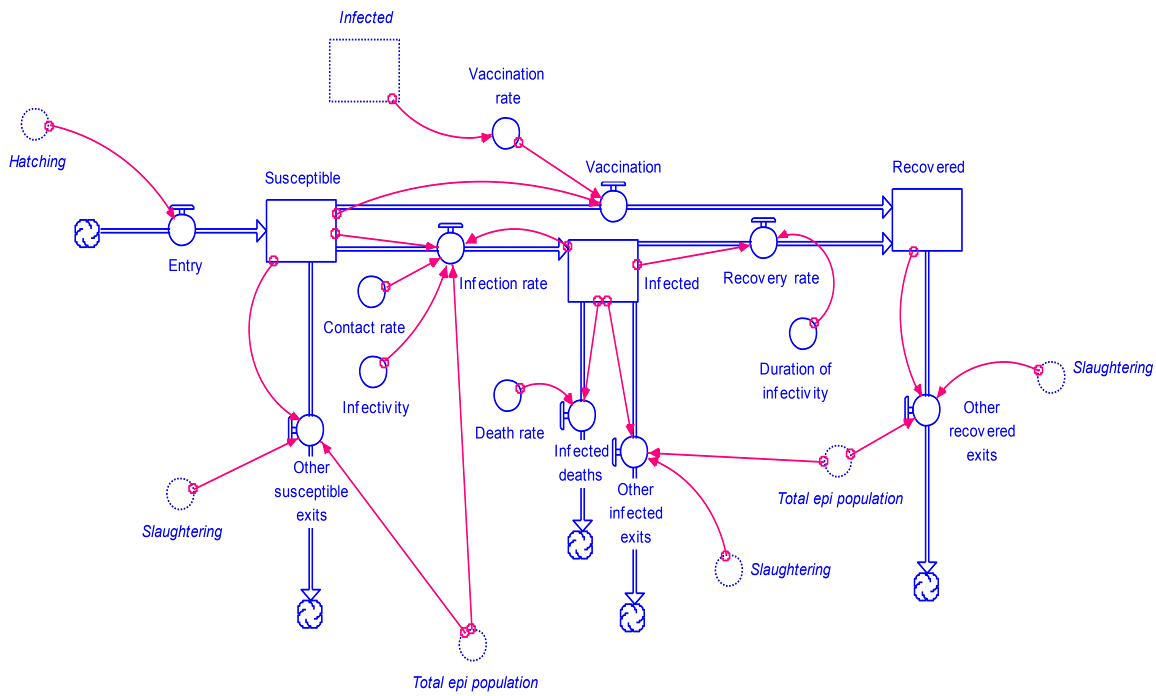


Figure 5: A epidemiological model of disease spread in STELLA for poultry

Source: Rich (2007)

When a disease is introduced, animals will move between the states Susceptible and Infected based on the product of (i) the rate of contact between susceptible and infected animals and (ii) the level of infectivity of the disease (β in equation (1)). Once infected, animals will either die from the disease depending on the rate of mortality inflicted by it or will recover after a certain period of time as noted by the duration of infectivity in the figure (α in equation (1)). We can model control measures such as vaccination (as shown in figure 6) by incorporating a transition rate directly between Susceptible and Removed, based on the rate of vaccination of susceptible animals. Other control measures that can be analyzed include movement controls, modeled by reducing the contact rate between susceptible and infected animals, and the stamping out of exposed, susceptible herds that can be modeled by including an additional flow of animals exiting the stock of susceptible animals and calibrated by the rate of contact slaughter.

Second, the economic model used characterizes the population dynamics of animals between different states of nature (based on animal ages). This model can then be integrated with the movement of supply, demand, and prices over time, or can be linked to downstream value chain actors engaged in trade, processing, and retail, who themselves mediate price information to upstream suppliers.

Figures 7 and 8 illustrate different population structures for livestock for poultry and livestock, respectively. The village level poultry model in figure 7 follows some of the dynamics reported in Rushton (1996). In this model, birds transition between the states Eggs, Chicks, Growers, and Breeding Stock, based on technical parameters for the time spent in each state (as well as parameters on natural mortality and offtake). The movement of birds from Growers to Breeding Stock will depend on the number of birds desired by producers to be held in stock and which is influenced by changes in market prices. As meat prices rise, producers will want to hold more birds in stock to take advantage of these price movements. On the demand side, birds that are slaughtered are held in inventory from which sales of poultry meat are drawn. The model assumes that retailers hold two weeks of inventory of poultry meat (this could be frozen meat, for example). Price changes arise from changes in meat inventories; these equilibrate supply and demand. When demand exceeds supply, inventories are drawn down below desired levels of inventory, causing prices to rise. This rise in prices reduces demand and increases supply to move supply and demand closer to equilibrium. Supply and demand do not equilibrate instantaneously, as the process of inventory adjustment may take many periods to settle down to equilibrium.

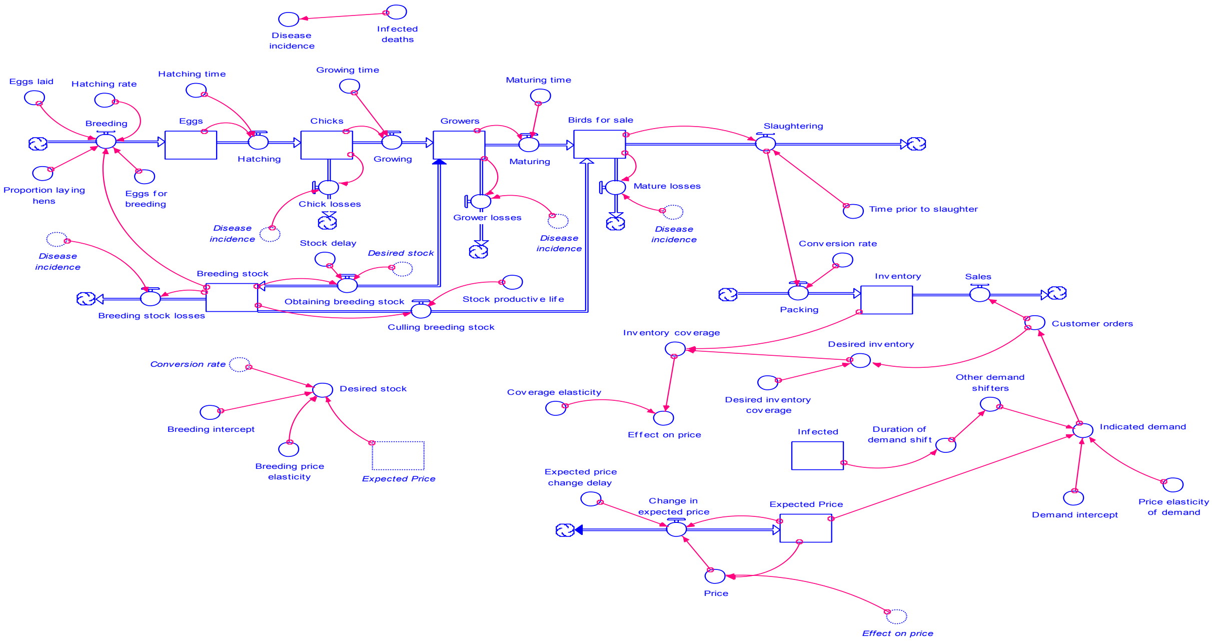


Figure 6: An economic model of poultry production in STELLA

Source: Rich (2007)

The cattle model in figure 7 provides a richer population structure than the poultry model in figure 6. This model – based on communal cattle production in Namibia (see Naziri et al. 2012) – is a STELLA parameterization of the DynMod model of Lesnoff et al. (2008) that was developed to measure livestock production growth in Africa. In this model, animals are subdivided into three population categories (Juveniles, Sub-adults, and Adults) and by gender (male and female). Animals remain in each of these states for a period of time determined by the analyst with transitions between states, as well as transitions to other interactions (e.g., offtakes of marketed animals, deaths of animals) also defined. In this model, pressures to sell or breed stock depend on the relative profitability of livestock production, defined in a simple model of farm-level revenues and costs (see figure 8). Prices are determined by downstream processors (figure 9) based on the export prices of meat in end markets for different cuts.

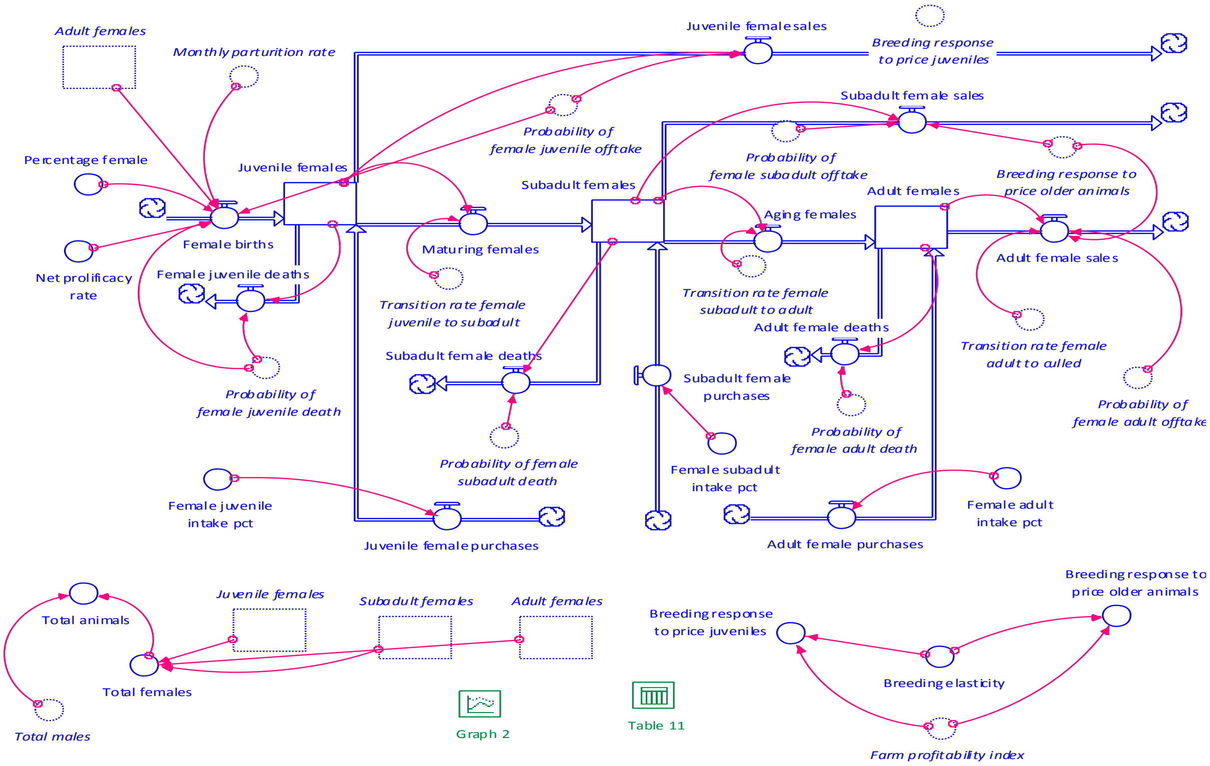


Figure 7: An economic model of cattle population and production in STELLA – female herd dynamics in Namibia

Source: Naziri et al. (2012)

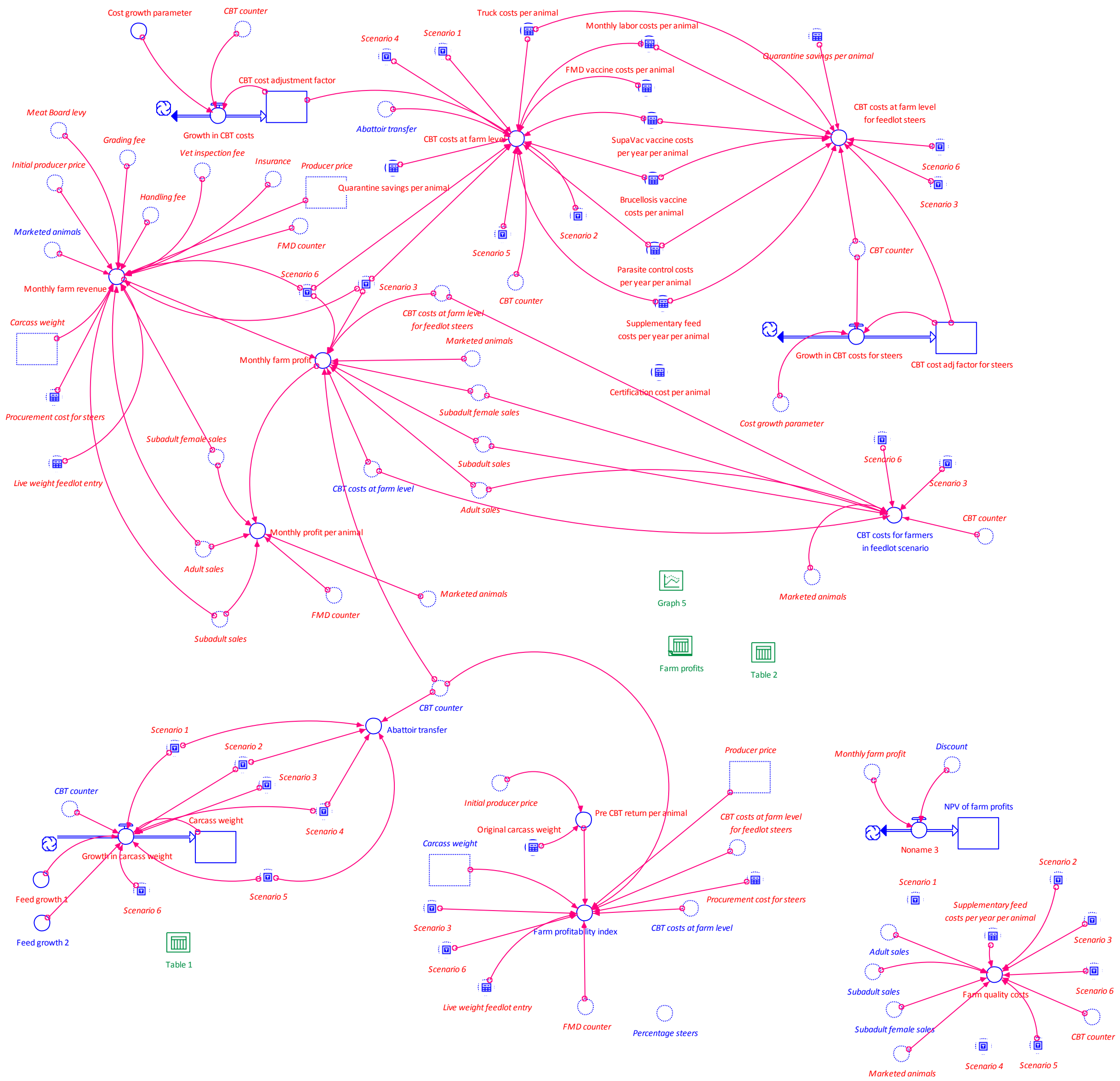


Figure 8: An economic model of cattle population and production in STELLA – farm profitability in Namibia

Source: Naziri et al. (2012)

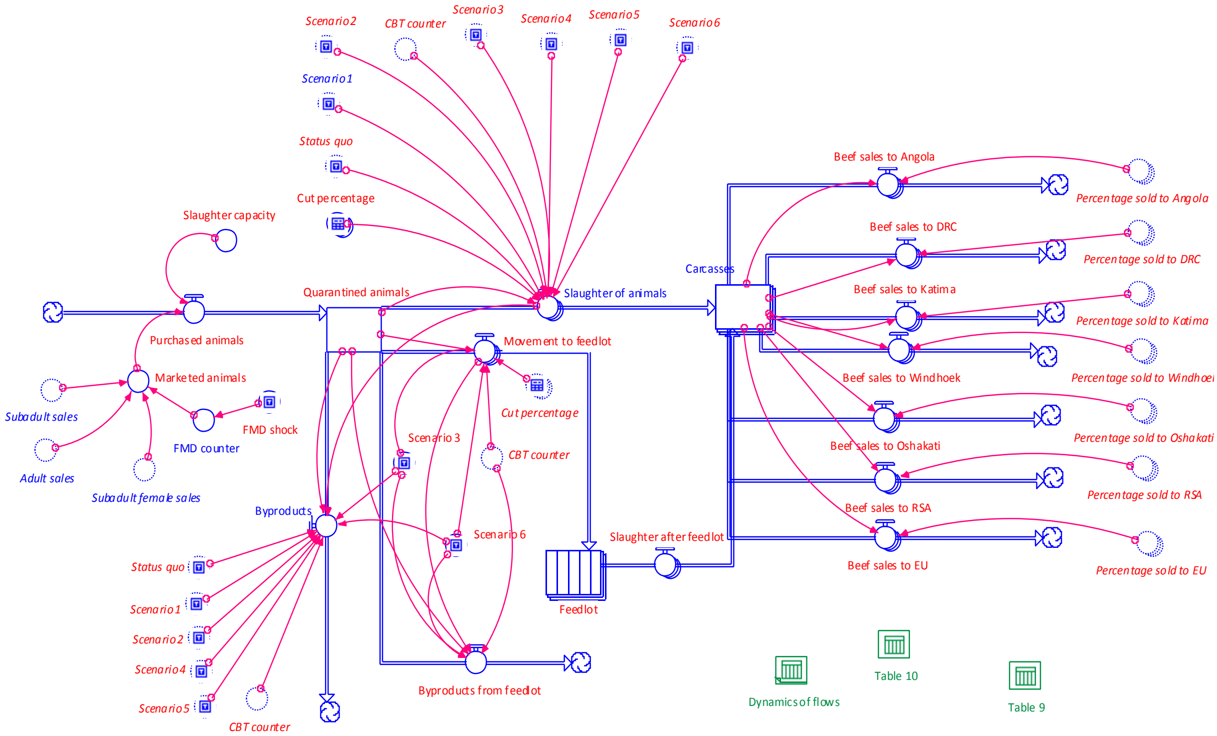
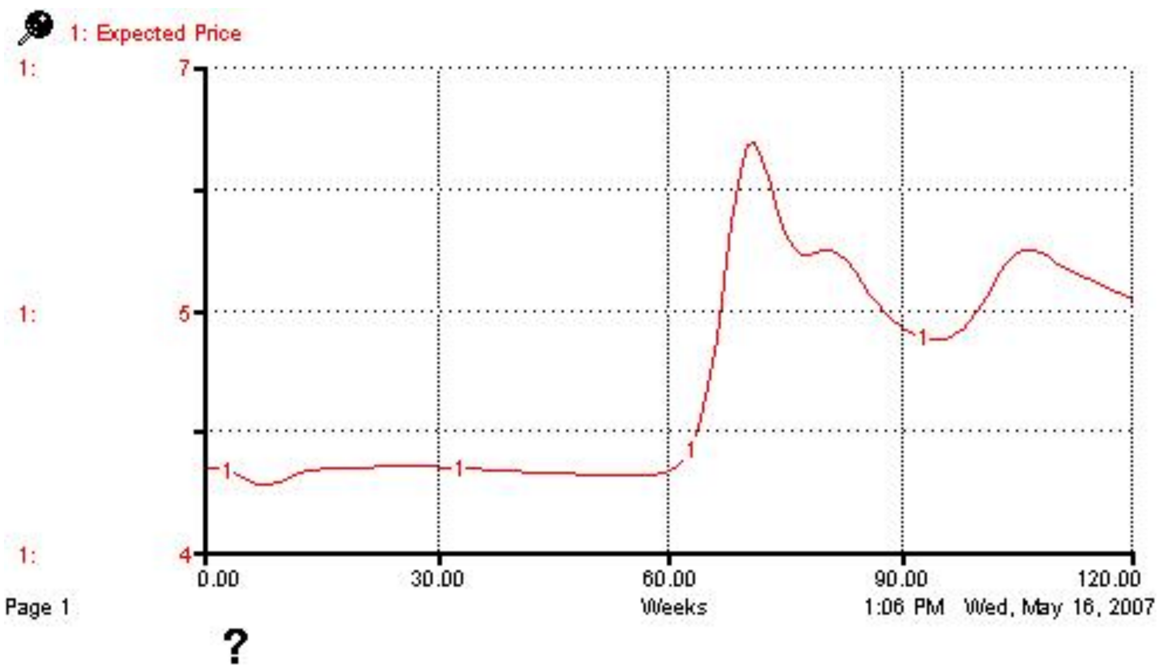


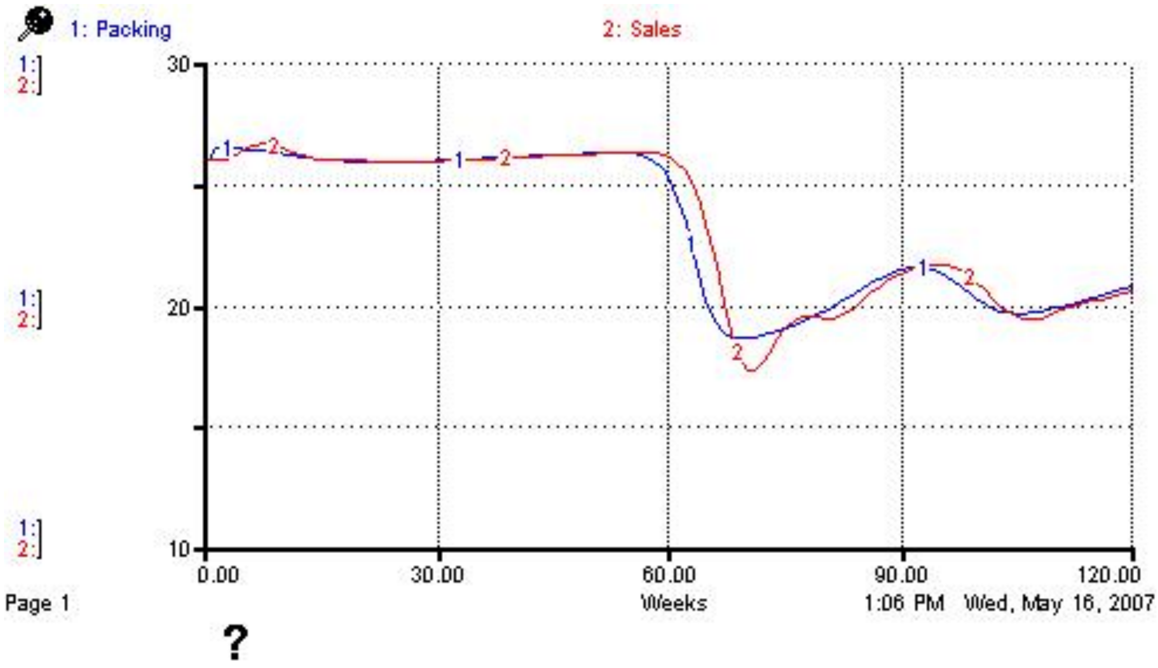
Figure 9: An economic model of cattle population and production in STELLA – abattoir dynamics and sales

Source: Naziri et al. (2012)

The integration of the two models requires three main adjustments. First, rates of entry and exit for the epidemiological model must be equivalent to the rates of breeding (or hatching) and slaughter in the economic model. Slaughter, offtake, and death rates must be distributed according to the proportion of animals in the epidemiological model that are in the states Susceptible, Infected, and Removed. This adjustment subsequently links the population dynamics with the evolution of the disease. Second, we must look at the feedbacks between epidemiology and the market and population dynamics in the economic model. In this case, the death rate in the epidemiological model that removes infected animals from the system must be distributed across the different states of age stocks in the economic model according to the proportion of the population in each stock. In addition, depending on the disease, there may also be impacts on demand. When this occurs, we can model a leftward shift in demand over the duration of the outbreak, which is measured by the number of time periods in which there are non-zero numbers of infected animals. Finally, we must have balance in our populations in our economic and epidemiological models i.e., the total stock of animals in the different population compartments of the economic model must be equal to the total number of animals in the states Susceptible, Infected, and Removed.

Figure 10 provides the results of one of the simulations reported in Rich (2007) applied to the proof-of-concept poultry model. The model runs using weekly time steps, with an outbreak seeded at the end of a one-year period in week 52 through the introduction of one infected bird. The first set of simulations modeled the impact of a hypothetical animal disease outbreak in which no control measures were taken and which killed one-quarter of the birds that were infected. Figure 10 highlights the changes in prices (panel 1), sales and packing (panel 2), animal stocks (panel 3), and the evolution of disease (panel 4) for a disease that has just a supply effect in the system (Rich (2007) presents the results of a second simulation in which there is a demand shock also). We note that there is a significant increase in prices, which however occurs with a lag, as the impact of the disease on the production cycle is delayed until enough affected stock would be due to be sent to market (figure 10, panels 1 and 2). These price increases cause a noticeable decline in sales which persists and remains below pre-disease levels even one year after the initial outbreak. The rise in prices induces a short-lived increase in demand for breeding stock to rebuild animal inventories once the outbreak has subsided, but subsequent waves of endemic disease depress animal stocks, causing lower and cyclical behavior in supply and demand (figure 10, panels 2 and 3). The lack of control efforts in the baseline creates dampened waves of disease that recur as new susceptible animals enter the system (figure 10, panel 4), with the peak infection occurring during the first outbreak.




1: Packing
2: Sales
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Weeks
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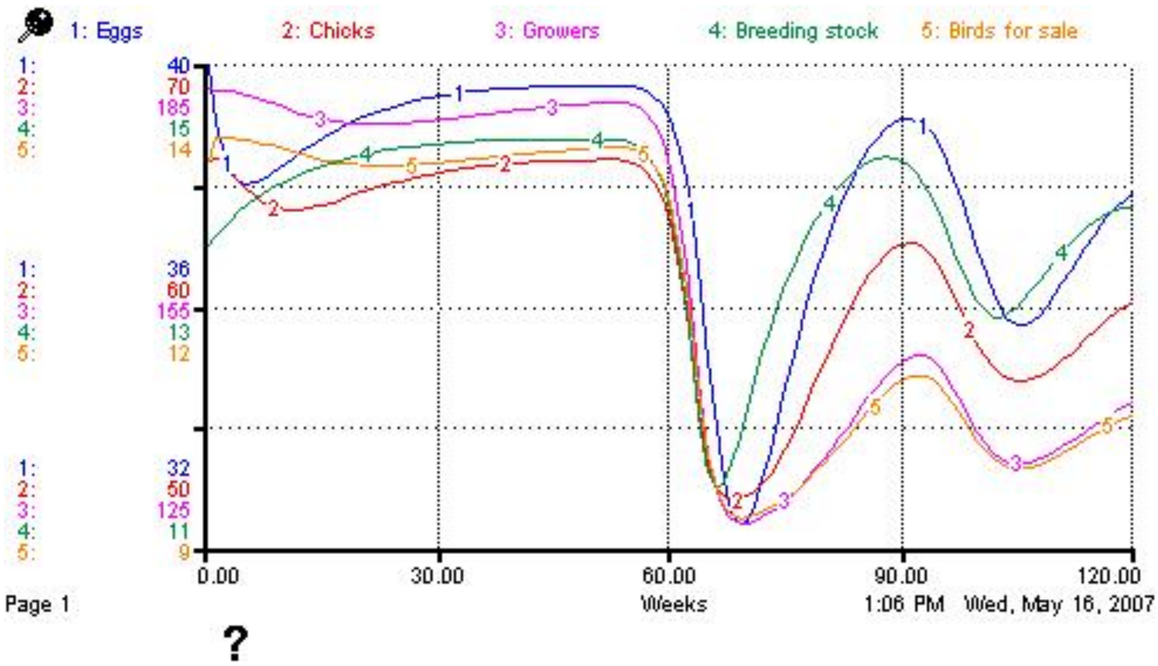
1: Eggs
2: Chicks
3: Growers
4: Breeding stock
5: Birds for sale
40
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15
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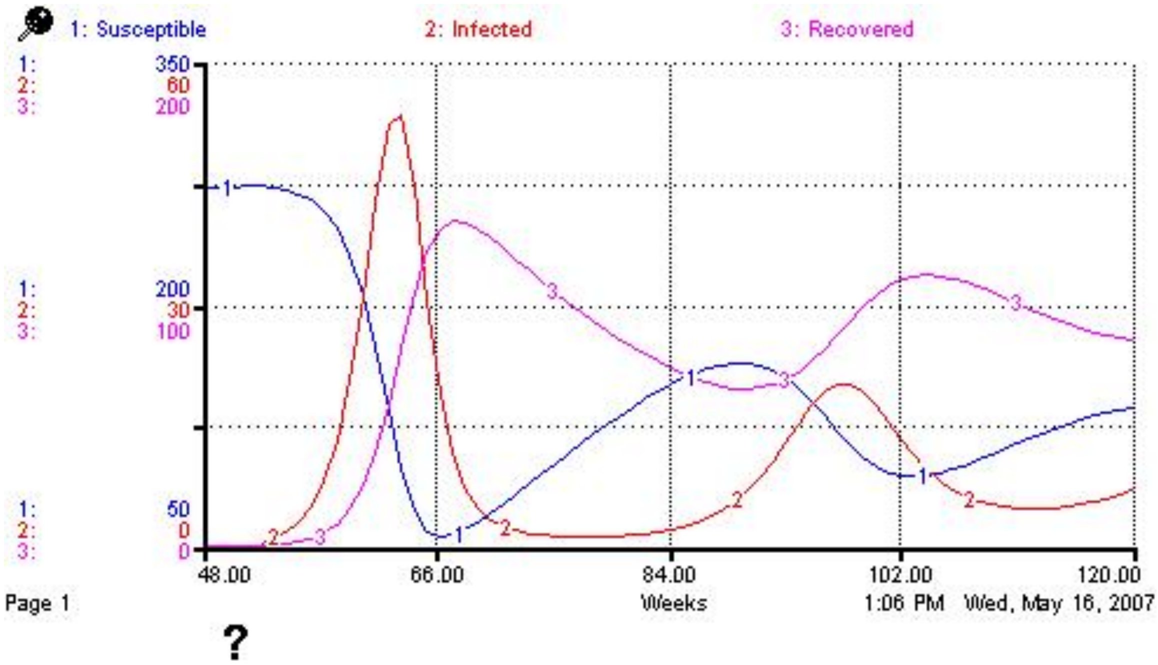


Figure 10: Impacts of a hypothetical disease outbreak in poultry (Rich 2007)

Figures 11 and 12 present results from a number of simulations conducted in Namibia with the model illustrated in figures 7 through 9. This model sought to calculate the profitability of different investments in biosecurity and disease control associated with implementing commodity-based trade protocols. In particular, the model assessed the tradeoffs between higher prices from better market access against the higher costs associated with one-time and recurrent expenditures on disease control measures. Simulation 7 (as labeled on the two figures) reflects the status quo in which there are regular outbreaks of FMD, depriving farmers and abattoirs of income due to abattoir closures and movement restrictions. Scenarios 1-3 look at progressively advanced initiatives that improve meat quality and biosecurity, with scenario 3 considering the development of a biosecure feedlot. Scenarios 4-6 are similar to 1-3 with the exception that they consider the construction of an EU-certified abattoir as well. All scenarios assume that FMD is controlled, unlike in the baseline. In the cases illustrated below, there are significant tradeoffs between negative impacts on abattoir income (figure 11) versus positive impacts on farm income (figure 12), with the net impact only being a very marginally positive change in the value chain as a whole (Naziri et al. 2012).

In the models above, we focus only on livestock systems *per se* and not their wider interactions with the agricultural economy, such as livestock's use as draught labour. However, it would be potentially possible to address this if information on the impacts of livestock disease on cropping patterns were available. An attempt to model this is described in section 4.

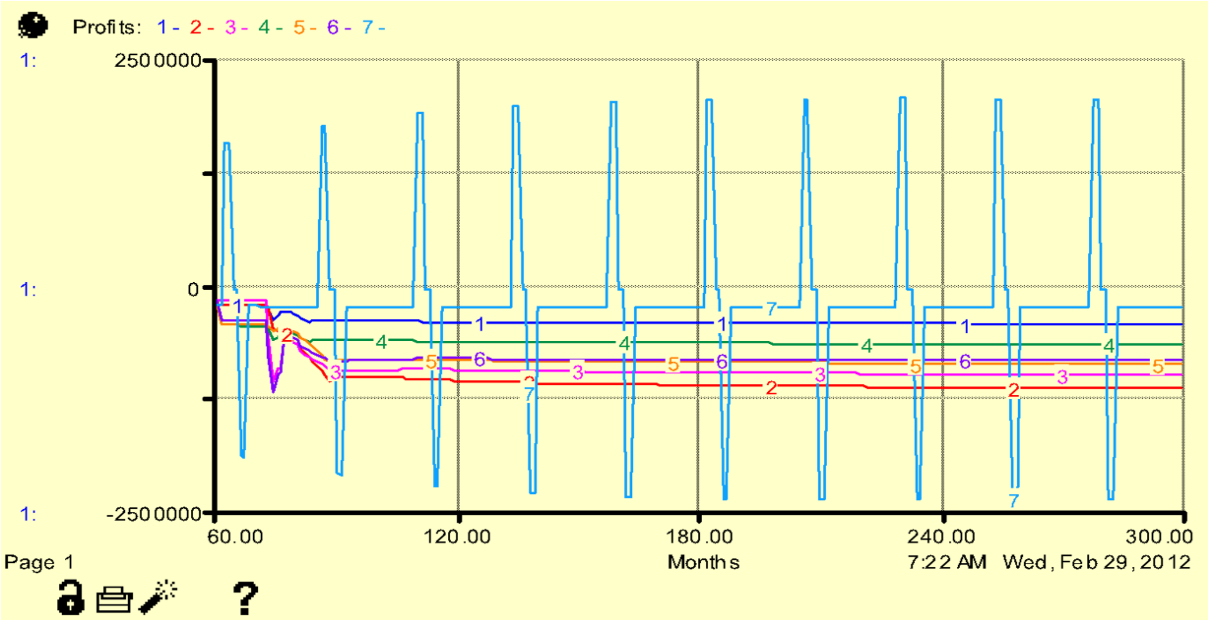


Figure 11: The dynamics of abattoir profits in alternative commodity-based trade scenarios in Namibia

Source: Naziri et al. (2012)

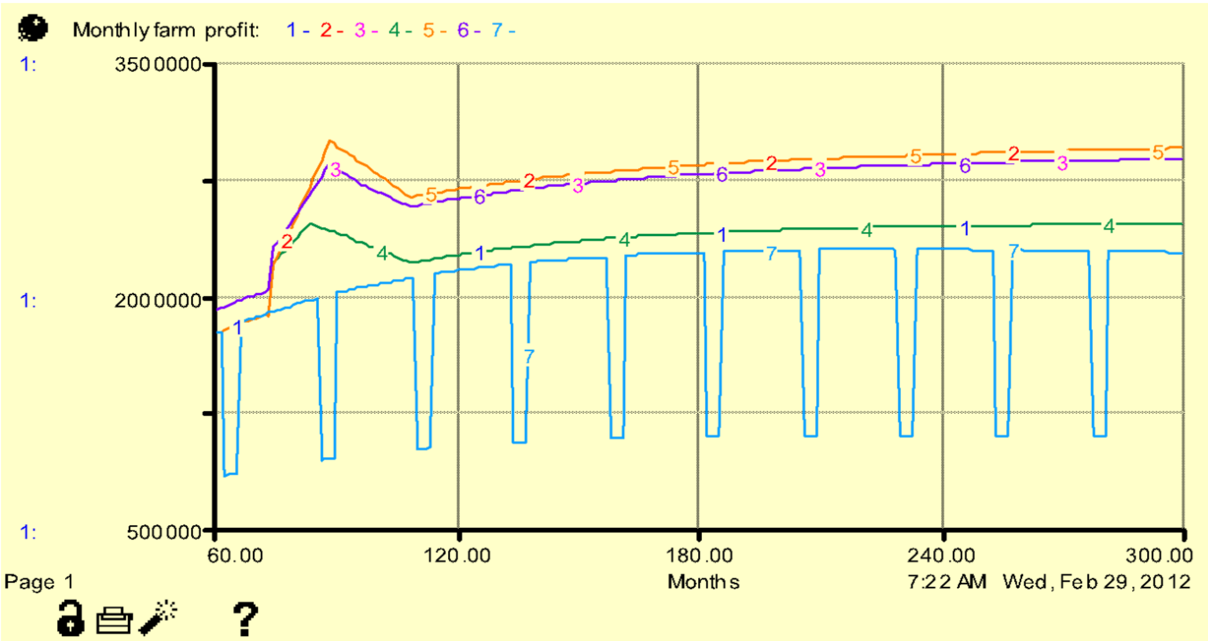


Figure 12: The dynamics of farm profits in alternative commodity-based trade scenarios in Namibia

Source: Naziri et al. (2012)

Data Requirements for Integrated Quantitative Value Chain Modeling

The data requirements for building an integrated model as discussed above can be found in table 3 below:

Table 3: Data requirements for developing integrated quantitative value chain models

Type of data	Description	Possible sources
Livestock demographics & population dynamics	• Initial stocks of animals • Shares of age/sex classes in livestock populations • Mortality rates by age/sex class • Average life span by sex • Parturition rate (by month) Net prolificacy rate (average proportion of animals born alive per parturition)	National statistics, farm surveys, interviews with key informants
Animal movements data	• Offtake rate by sex/age class • Movements of animals to/from region	Farm surveys, interviews with key informants
Elasticities	• Supply • Demand • Income	Derived from household surveys, published estimates
Value chain process variables	• Period of time taken between farm sales and market arrivals • Period of time taken between sales from farms and slaughter (weeks) • Inventories of meat (weeks)	Farm/trader/processor surveys
FMD epidemiological data	• Contact rates between animals • Between-farm contact rates • Infectivity of FMD • Mortality rates of FMD by age/sex • FMD vaccination coverage • FMD incidence rates (this is a result of some of the	Farm surveys, interviews with Veterinary Services, epidemiology literature

Type of data	Description	Possible sources
	above)	
Market prices	• Prices of animals by sex/age class • Prices of meat by cut • Prices of major crops • Rental prices of animals for draught labor • GDP and GDP per capita	Farm/trader surveys, national statistics, interviews with processors/retailers
FMD control costs	• Medicine costs • Additional feed costs • Treatment costs (includes bullet 1?) • Vaccination cost	Farm surveys, interviews with Veterinary Services
Draught labor parameters	• Number of animals used per hectare • Duration animals used for plowing • Time of the year animals used • Yields of rice/other crops using draught labor • Yield loss associated with lack of draught labor • Time animals unavailable for draught labor due to FMD	Farm/trader surveys, national statistics, interviews with Veterinary Services and Extension Services

Economywide Perspectives on High Impact Animal Diseases (Social Accounting Matrices and Methods)

Detailed and rigorous accounting practices always have been at the foundation of sound and sustainable economic policy. A consistent set of real data on the economy is likewise a prerequisite to serious empirical work with economic simulation model. For this reason, a complete economywide scenario analysis facility stands on two legs: a consistent economywide database and modeling methodology. This chapter gives an overview of the accounting conventions used in applied general equilibrium modeling.

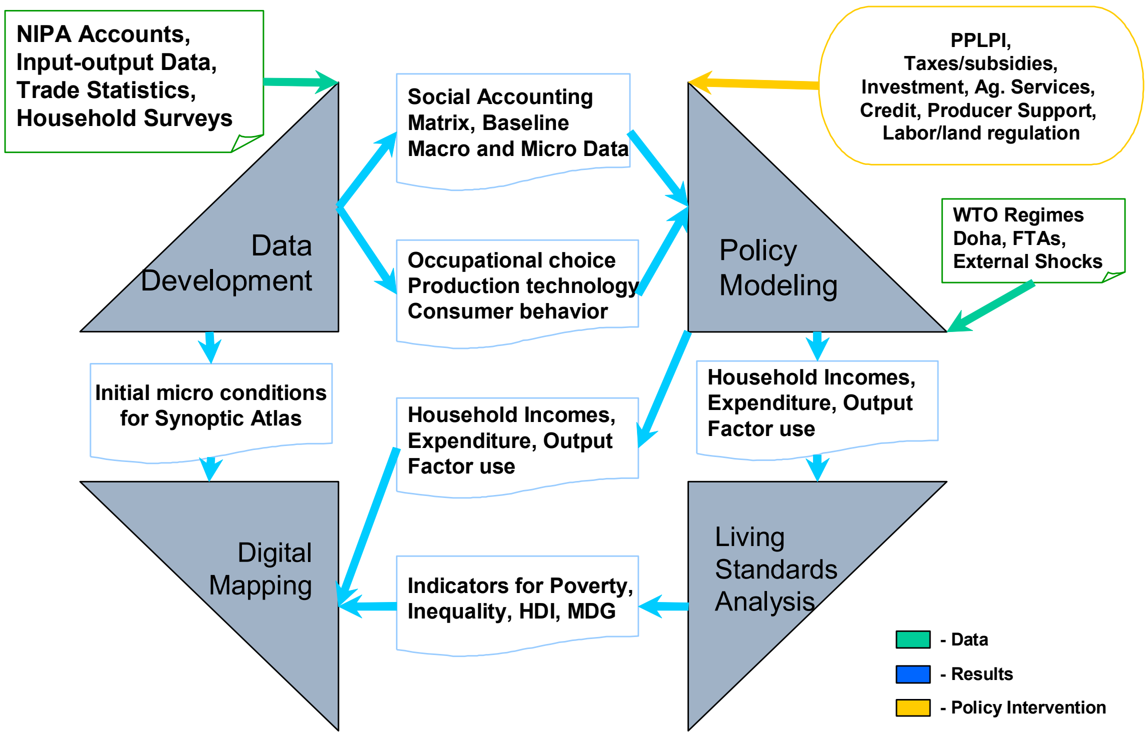
The three governing criteria for development and maintenance of good economywide data are detail, consistency, and currency. Detail in the context of CGE models refers to industrial and domestic institutional (e.g. household) classification, and to capture this, the database should incorporate input-output accounts and other transactions tables. Economywide consistency is achieved primarily by reconciling the input-output accounting information with the standard National Income and Product Accounts (NIPA) such as those published for the United States. This reconciliation is accomplished and maintained with a social accounting matrix (SAM), which details economywide transactions between firms, households, government, and other domestic and foreign institutions at a flexible level of disaggregation. This SAM and other components of the database are estimated to a uniform standard, consistent with observable information in a single base year.

The discussion below gives general indications about the many sources of data, their unification in the SAM and subsidiary accounts, and the numerical and statistical reconciliation procedures that are used. A typical database development project relies on an extensive applied and theoretical literature, and no attempt is made here to give an exhaustive survey.

Economywide Policy Simulation

As a central component of economywide assessment methodology, we use general equilibrium models to shed light on the local impacts of animal disease risk and response. In an era of globalization, there is a generally held belief that greater national and external market integration can confer aggregate growth benefits in the form of higher incomes and more diverse production and consumption opportunities. Despite this view, however, the detailed incidence of market linkages is not so easy to generalize. Indeed, policies targeted at agrifood development in general, and the livestock sector in particular, need a solid empirical basis to identify the detailed costs and benefits of market interactions.

Figure 13: Detailed Facility for Economywide Economic Assessment



In today's world, economic linkages are so complex that it is unlikely that policy makers who rely on intuition alone will achieve anything approaching optimality. Indeed, much evidence now suggests that indirect effects of many policies outweigh direct effects and, if not adequately understood, can substantially offset or even reverse them. Because of their abilities to capture exactly such linkages, computable general equilibrium (CGE) models have become preferred tools for tracing supply and demand linkages across extended chains of price-directed exchange. Because of their detailed behavioral specification, these models are particularly good at elucidating adjustments in income distribution and indirect impacts on economic activity. The basic objective of this approach is to support more evidence-based livestock policies with deeper insight into economic conditions, behaviour, and market linkages. The general analytical facility consists of four components, depicted in figure 4 above.

Data Requirements

Traditionally, the database for models with sectoral detail was the input-output accounting tableau, which captures industry linkages through flows of intermediate and factor input. Although it provides sectoral disaggregation, an input-output model does not include enough institutional detail to provide a framework for considering the full impact of policy on an economy. The input-output accounts can be extended to capture income and expenditure flows between other institutions, such as households, government, and the rest of the world in a SAM. Indeed, the development of SAMs was motivated in part by the desire for a unified framework that reconciled input-output accounts with NIPA accounts. The SAM thus provides detail and an economywide policy perspective in a consistent accounting framework.

Expected Outputs

The direct outputs of the economywide assessment training will be knowledge products in the hands of national technical experts. Ultimately, however, the goal of the training is to see these tools applied to domestic animal disease risk and response assessment, including support of public-private risk and response communication. Recent history of high impact animal diseases shows us that the quality of this communication can be an essential component to effective public compliance with risk reduction programs, as well as promoting more expedient and effective response measures. By implementing a uniform standard for evidence and analysis in all countries, it is also hoped that these tools will promote regional dialog and higher standards for evidence based policy coherence.

Technically, the outputs of this phase of capacity development will include new data resources, assembled and synthesizes to more uniform standards, as well as a potential stream of results from the scenario analysis tools that comprise the main analytical capacity. After these are transferred to national counterparts, we plan to initiate specific scenario research activities that achieve two essential objectives: 1) Immediate and relevant hands-on experience with the new data and analysis tools, 2) new knowledge products for risk and response communication by those who complete the program.

Integrating Supply Chain and Economywide Perspectives

The models described in sections 3.1 and 3.2 are typically constructed independently, given that economywide models tend to look more at macro-level phenomenon, while value chain models tend to focus at the farm, village, or regional level. However, it is possible to consider ways of linking these models further. For instance, a multiplier analysis from a SAM/CGE analysis will provide the decomposed income impacts associated with a livestock disease (based on different farm/household types) at a given period of time. Normally, a SAM/CGE analysis will give the final year impact, but it is possible that a path of intermediate impacts could be calculated based on the progression of disease. In other words, an epidemiological model could give the impact of a disease for each period of time (say, a weekly time step). This initial impact could be fed into a SAM multiplier matrix to derive an initial impact on income. This type of impact could be subsequently seeded into an SD model as an income shock to demand, shifting the demand curve (recall figure 7) and involving the evolution of prices (and livestock populations) in subsequent periods, as well as influencing the progression of disease in the next period. This process could be repeated week-by-week, provided the SAM multiplier matrix was endogenized in the SD model.

A Case Study of FMD Control in Cambodia

In this section, we describe a proof-of-concept model developed to analyze the integrated impact of FMD. This model follows the quantitative value chain approach discussed in the previous section, combining the evolution and feedbacks between four interrelated models – a model of disease spread, a model of livestock herd evolution, a model of meat sales, and a model of rice production. We apply this model to Cambodia, where initial baseline data was collected, although additional data will be necessary to fully validate the results presented later in this section. Nonetheless, this approach illustrates a means by which direct and indirect impacts at the sector and value chain level can be directly integrated with models of disease spread, and subsequently provide a more realistic perspective on the impacts and consequences of different disease control interventions.

Background Information

FAOSTAT data reveal that Cambodia had stocks of 702,074 buffaloes, 3.48 million cattle, and 2.06 million pigs in 2010. Stocks of cattle and buffaloes have been declining, due to increased feed costs, mechanization, and losses associated with transboundary diseases, particularly FMD and haemorrhagic septicaemia (HS) (Young et al. 2012). Most livestock production in Cambodia is small-scale and backyard oriented, although semi-intensive, peri-urban production is increasing to meet rising urban demand (Gleeson 2002; Shankar et al. 2012). Transboundary trade is high, though large informal, militating against government desires for establishing disease-free stocks (Shankar et al. 2012).

FMD incidence in Cambodia is high, fueled by transboundary movements of animals and communal grazing of animals (Shankar et al. 2012). Vaccination against the disease is low, estimated at less than 3 percent by Young et al. (2012). Economic impacts at the farm-level conducted by Shankar et al. (2012) and Young et al. (2012) reveal significant negative effects arising from FMD outbreaks. Young et al. (2012) found farm losses ranging from US$216 to US$371, taking into account treatment costs and varying based on whether an animal died and was replaced at the farm level. Shankar et al. (2012) found smaller short-term, FMD-associated costs (an average of US$67 per household), but quantified this from the standpoint of overall household income. In this context, average FMD-related costs as a percentage of infected household income were reported at 7.4 percent, with greater losses (11.7 percent) among poorer households.

Table 4 summarizes these impacts of FMD in Cambodia based on the framework presented in section 2. The framework notes particularly strong impacts of disease at lower levels of impact i.e., farm and sector, with pronounced impacts downstream in the agricultural sector given the interaction of buffaloes and crops. Economywide impacts of FMD are nuanced, related primarily to the transboundary movement of animals into Cambodia and the impacts such movements have on the economy at large. On the other hand, formal sector impacts of FMD on international trade are relatively small.

Table 4: Conceptual framework for FMD impact assessment in Cambodia

Dimension of impact	**Disease characteristics by level of analysis**					
	Level 1: Farm	***Level 2: Cattle sector***	***Level 3: Livestock sector***	***Level 4: Agricultural/ Value-chain***	***Level 5: National***	***Level 6: Global***
Disease characteristics						
Severity of disease	High morbidity of disease, with higher mortality impacts on pigs			Strong (though decreasing) impacts on animal traction and agricultural crop yields		
Frequency	Endemic, with higher impacts when outbreaks coincide with planting cycles					
Mode of transmission	Animal contacts					
Spatial spread	Transboundary fuelled by animal movements (local, regional, and global)					
Public health	None					
Production characteristics						
Production system	Largely informal, with semi-intensive piggeries increasing in importance	Predominance of traditional, informal markets, loose value chain linkages				
Production cycle	Medium production cycles for pigs, long-term for cattle/buffaloes					
Population size	Moderate populations of pigs and cattle					Net importer of animals from other GMS countries
Importance of by-products	High, particularly in terms milk, manure, and animal traction					
Market characteristics						
Level of commercialization and market integration	Smallholder and commercial sectors both affected, though smallholders mainly affected downstream			Impacts pronounced on smallholder crop yields		Informal marketing problematic for transboundary spread; high demand fuels trade
Scope of value chains	Relatively simple, arms-length transactions, with limited value-adding or innovation downstream					
Non-sector impacts				Impacts pronounced on smallholder crop yields		

Dimension of impact	Disease characteristics by level of analysis					
	Level 1: Farm	***Level 2: Cattle sector***	***Level 3: Livestock sector***	***Level 4: Agricultural/ Value-chain***	***Level 5: National***	***Level 6: Global***
Level of socio-economic development	Generally low in affected regions					
Livelihoods characteristics						
Role of livestock in livelihoods	High for semi-formal production; part of diversification strategy for smallholders					
Cultural importance of livestock	Limited					
Control characteristics						
Effectiveness of current control technologies	Vaccine exists, but limited use (< 3 percent)					
Resource requirements for control	Costs associated with vaccines, delivery, and laboratories					
Maintenance costs for control	Monitoring and surveillance critical					Coordination necessary across borders
Externalities related to disease control						
Institutional capacity	Strong official commitment, but limited capacity for on-the-ground control					

Cambodian counterparts proposed an impact assessment of FMD (and possibly HS) at the sector level, focusing particularly on cattle and buffalo. Some data that is thought to be available on FMD incidence, losses, and control costs have been identified, but more data is required on coping strategies and related production and marketing practices, the role of cattle in livelihoods, and the asset characteristics of livestock-keeping households.

Model Description

The integrated FMD model follows the modelling principles discussed in section 3. We constructed a system dynamics (SD) model using the iThink software, version 10.0 (http://www.iseesystems.com). One of the benefits of using software such as iThink or STELLA is the ability to build user interfaces that allow the user to run various policy simulations (including sensitivity analysis) without a need to alter the model structure or to run a full copy of the software; the free demo mode is sufficient. The full user interface includes tables for data parameters, sliders that adjust parameters related to disease spread and market response, and several graphs that illustrate the evolution of impacts on key parameters of interest (herd numbers, prices, sales, infected animals).

Figures 14 and 15 show the data tables used in the interface. These data can be directly entered by the user into the table and reflect information on herd dynamics and transition rates between states (figure 14) and various parameters associated with prices, production levels, land area, yield, price response (elasticities), and costs related to FMD control (figure 15). Data in figure 14 comes from herd demographic parameters obtained in Cambodia, while the transition rates between states are the baseline rates using the DynMod model which is the basis for the herd population model. Initial stocks are denoted as thousand animals, with data here based on cattle populations in Cambodia only (not buffalo). Data in figure 15 were obtained from FAOSTAT and collected field data, with the exception of rice elasticity figures which borrow figures from Minot and Goletti (1998) for Viet Nam, meat elasticity and carcass weight figures, which were assumed by the authors, and real GDP per capita growth rate figures which were obtained from Penn World Tables.

Herd dynamics

Share juvenile males	0.1014
Share subadult males	0.1014
Share adult males	0.2881
Share juvenile females	0.08142
Share subadult females	0.13231
Share adult females	0.29175
Initial stocks	3377
Net prolificacy rate	0.9
Annual parturition rate	0.5
Annual female adult hazard rate deaths	0.058
Annual female adult hazard rate offtakes	0.01348
Annual female subadult hazard rate deaths	0.058
Annual female subadult hazard rate offtakes	0.01348
Annual female juvenile hazard rate deaths	0.112
Annual female juvenile hazard rate offtakes	0.10962
Annual male adult hazard rate deaths	0.051
Annual male adult hazard rate offtakes	0.276
Annual male juvenile hazard rate deaths	0.102
Annual male juvenile hazard rate offtakes	0.34
Annual male subadult hazard rate deaths	0.051
Annual male subadult hazard rate offtakes	0.276
FMD abortion rate	0.5

Figure 14: Interface for tabular data on herd dynamics

Market parameters

Carcass weight adult females sold	170
Carcass weight adult males sold	200
Carcass weight subadult females sold	140
Carcass weight subadult males sold	150
Total population in Cambodia	1.4138e+07
Per capita kgs bovine meat consumption	5
Baseline meat price	10
Initial animal price	510
Supply elasticity for animal sales	0.2
Breeding elasticity	-0.2
Baseline rice yield	3
Price elasticity of supply for paddy	0.34
Initial area under paddy 000 acres	2926
Baseline paddy production	8.779e+06
Exports	205717
Net stocks	438950
Conversion rate paddy to rice	0.65
Food use percentage	0.85
Baseline rice price	0.465
Price elasticity of demand for rice	-0.29
Real GDP per capita...er year 2001 to 2010	0.057
FMD GDP reduction parameter	0
FMD yield reduction	0.1
Unit vaccination price	2.5
Unit cost of production	650
Unit treatment price	20

Figure 15: Interface for data on market parameters

Figure 16 denote "sliders" that parameterize different disease-related assumptions in the model. These allow the analyst to change assumptions related to contact rates, infectivity rates, death rates, size of initial outbreak (in terms of number of animals affected), duration of infectivity, week in which an outbreak begins, vaccination coverage and delays in initiating a vaccination campaign, volumes of distress sales by producers, proportion of markets remaining open during an outbreak, and amount of paddy land impacted by FMD. Graphs comparing output from different simulations are found at the bottom of the interface, with results described in the next section.

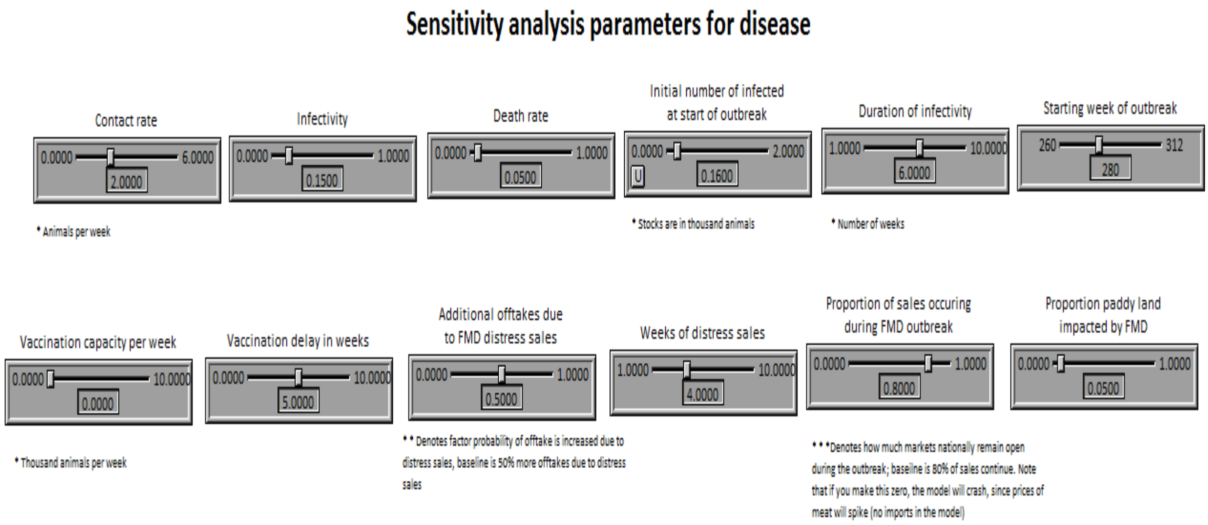


Figure 16: Interface for data on FMD parameters

Behind the interface layer is the model, which is comprised of four modules. The first module is a herd population module based on DynMod and analogous to the model described in figure 7 in section 3. The second module is a simple SIR model of disease spread akin to the model described in figure 5 in section 3. The final two modules look at downstream markets, one directly impacted by FMD (beef), the other indirectly impacted (rice) on account of cattle use for draught labor. Figure 17 illustrates the beef model in iThink. In common with all SD models of supply and demand, price changes are modulated by inventories in the model, with excess inventories (relative to a target, defined as a fixed number of weeks (2 weeks for meat) times demand) causing prices to fall and deficit inventories (relative to the target) causing prices to rise. Demand is specified simply as a function of its own price and income (GDP) per capita in log-linear form.

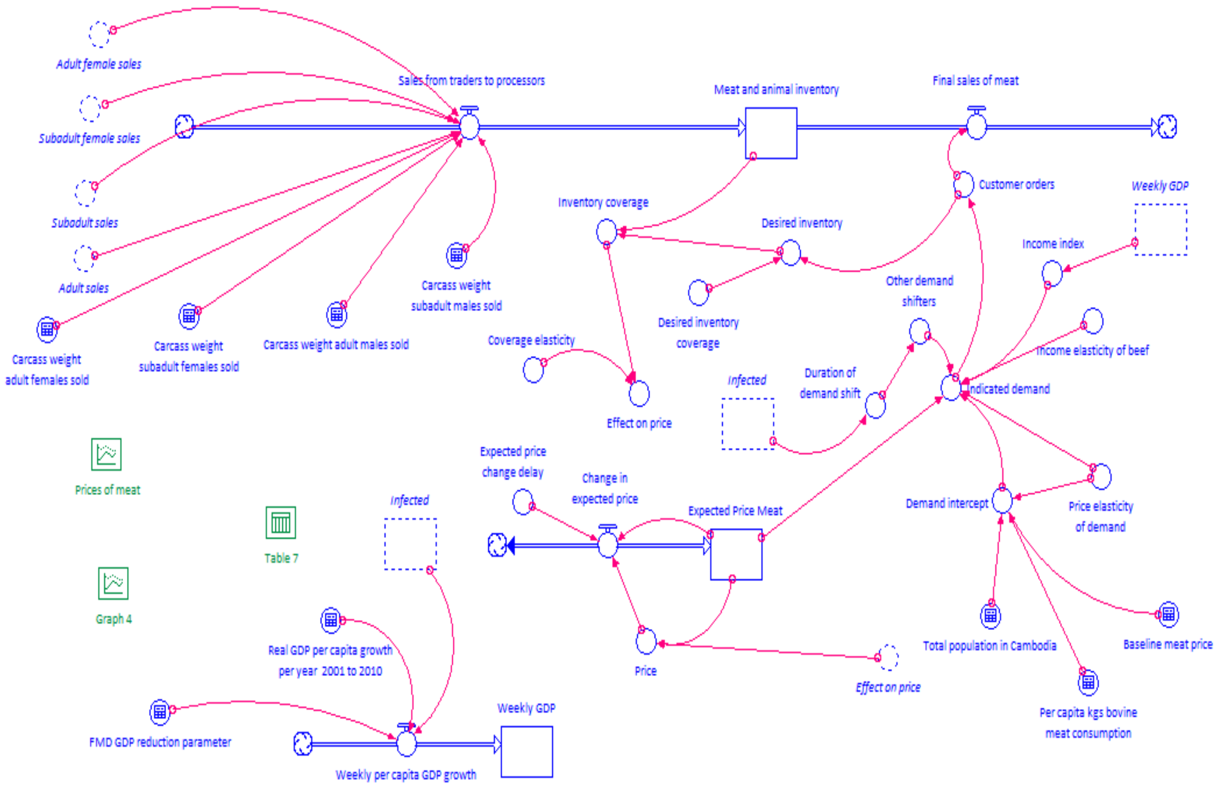


Figure 17: Module for the meat sector

Figure 18 illustrates the rice module. The rice module is similar in structure to the meat module, in that a similar inventory condition regulates supply and demand and demand is modeled as a log-linear function of prices and income. However, the functioning of the rice sector is rather different due to the dynamics of planting. In the model, we assume that planting occurs only during weeks 17-28 each year, after which rice moves to the stock "stocks of rice" where it remains until harvest at the end of the year. Harvested rice for consumption is then stored in the stock "Storage;" consumption of rice draws down these stocks throughout the year. This is in contrast to the meat sector in which meat is supplied consistently throughout the year. We further assume that FMD influences yields based on when in the planting cycle FMD first arises. We assume that FMD reduces yield by 100 kg/ha per week during those weeks that FMD affects farms during planting. The influence of FMD on aggregate rice production in Cambodia is relatively mild; expert consultation revealed that most farmers rely on tractors instead of draught cattle, with perhaps just 5 percent of farmers wholly utilizing draught labor. We use this 5 percent figure in our model to develop a weighted average yield based on the impact of FMD.

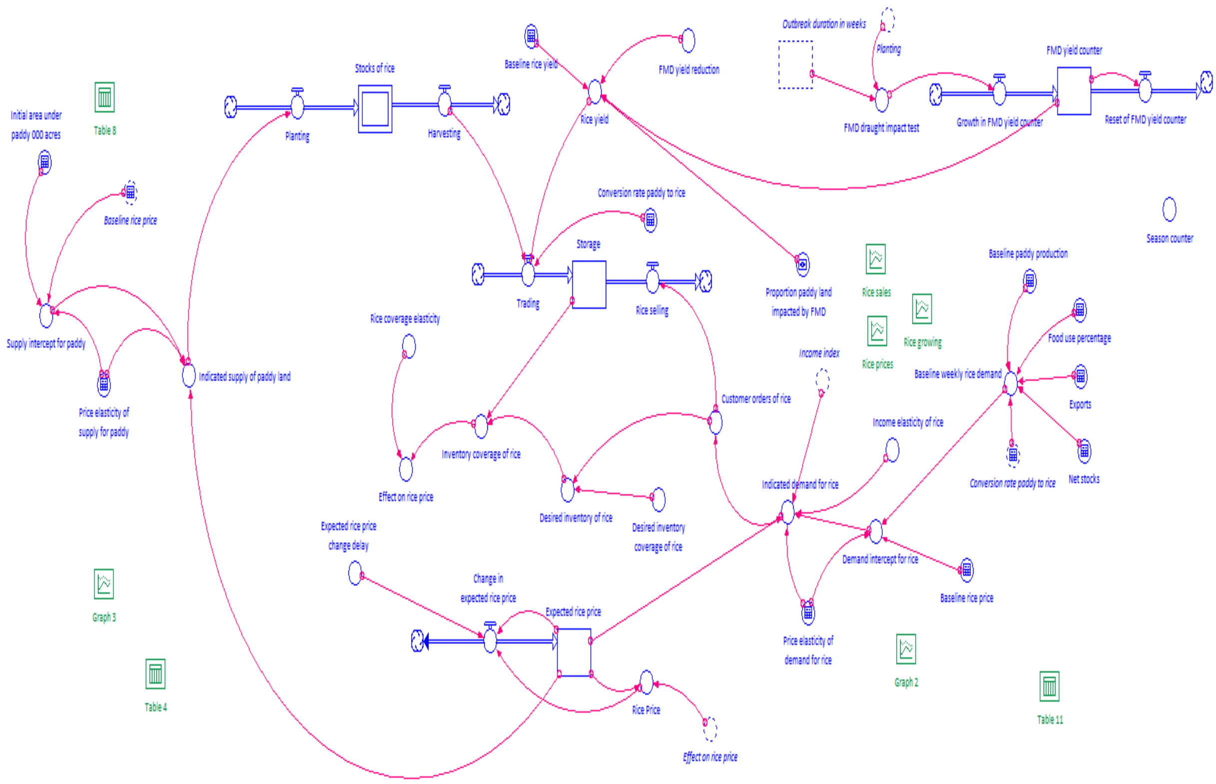


Figure 18: Module for the rice sector

Figure 19 illustrates the feedback structures that exist in the model, which highlight the importance of incorporating the interactions between sectors to get a more complete understanding on the impact of FMD. Disease outbreaks directly impact herd size, both in terms of direct mortality losses, but also in terms of sales of animals to markets, whether due to distress sales or because of price changes in the meat market. Conversely, disease-induced sales of animals alter the susceptible population to disease. In this model, where we do not spatially differentiate between markets and where sold animals are directly transformed into meat, susceptible animal populations fall as a result of disease-induced sales, potentially dampening the impact of disease. Where animals are sold to other more distant-markets as live animal sales to other farmers, such sales could exacerbate the spread of disease to other regions. Changes in meat prices influence future period sales of animals, which in turn influence the course of an outbreak over time as well. In the rice market, lower animal stocks influence rice yields, causing production to fall and prices to rise, influencing planting decisions made in future time periods.

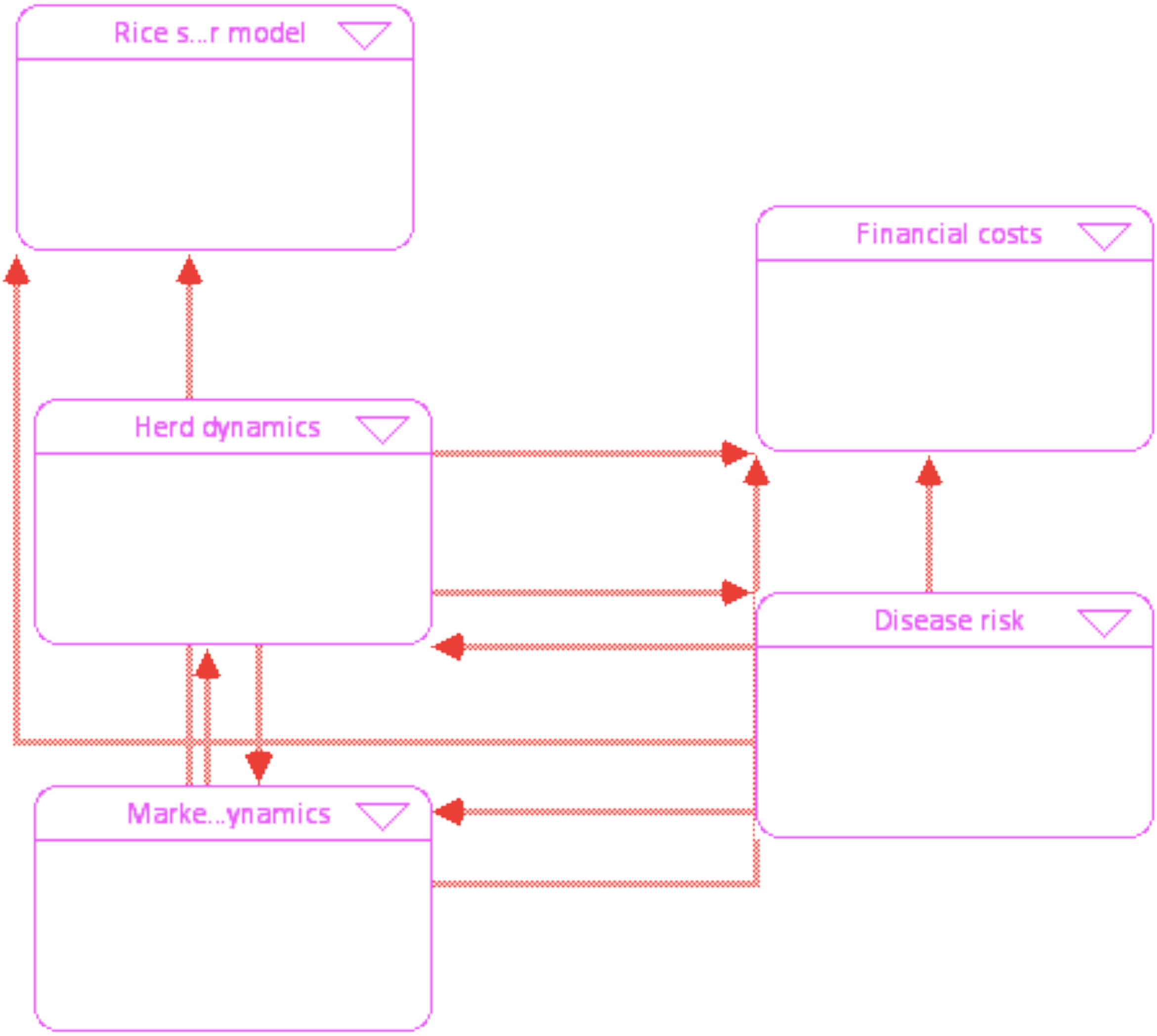


Figure 19: Feedbacks between different sector modules

We note that considerable extensions are possible with this model. As constructed, the model only considers national-level impacts in which inter-regional trade does not occur. However, with disaggregated data and information on animal movements, we could use a similar framework to examine disease-economic interactions within and between regions (see Rich 2008 for an example of an inter-regional SIR model for FMD developed in STELLA). These types of characteristics are extremely important in the context of the GMS and represent a future extension of this approach.

Preliminary Model Results

A number of preliminary proof-of concept simulations performed were:

1. A baseline scenario (status quo) against which to compare results from other scenarios, with production data and population evolution calibrated to fit population growth in Cambodia (about 1.5% per year);
2. An initial FMD outbreak in week 280 affecting an initial group of 1,000 animals. We assume 20% of markets are closed during the outbreak until less than 1% of the population is infected – at this point, 90% of markets open. Once the proportion of infected animals is less than 0.02%, we assume all markets re-open;
3. A similar sized outbreak as in (2) but in which distress sales last for 10 weeks instead of 4;
4. A similar sized outbreak as in (2) but in which 60% of markets are open during the major part of the outbreak (instead of 80% as in (2);
5. A similar sized outbreak as in (2) but where paddy crops affected by FMD are 27% instead of 5%, with the latter figure based on estimates found in Young et al. (2012);

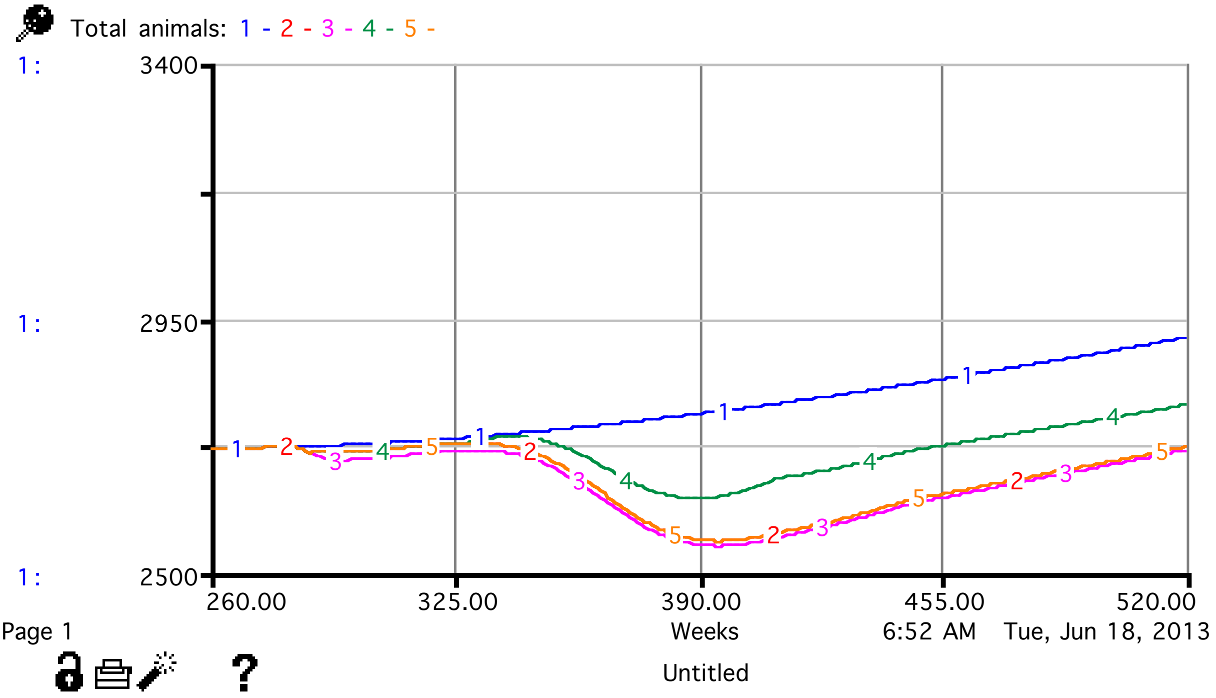
We can summarize these initial scenarios in the table below (table 5)

Table 5: Conceptual framework for FMD impact assessment in Cambodia: market scenarios

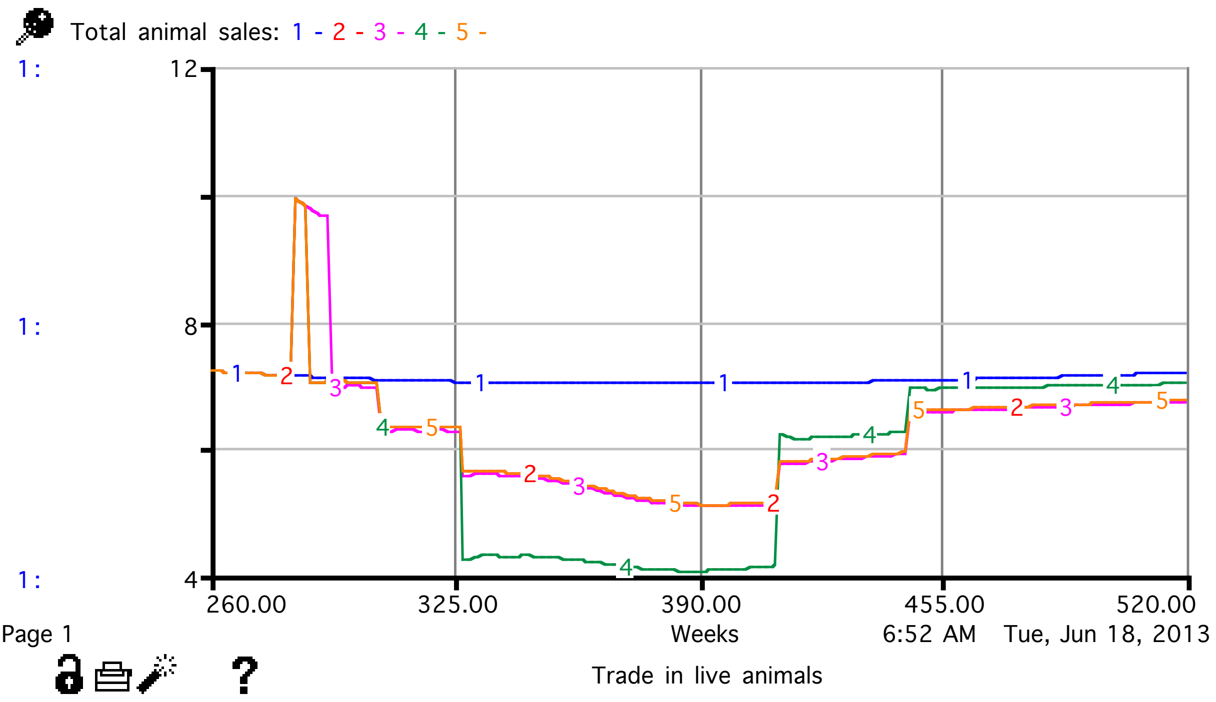
	Initial number of animals infected with FMD	Distress sale period	Markets closed	Paddy affected
S1	*Baseline: No FMD outbreak*			
S2	1,000	4 weeks	20%	5%
S3	1,000	10 weeks	20%	5%
S4	1,000	4 weeks	40%	5%
S5	1,000	4 weeks	20%	27%

We illustrate the results from the scenarios in figure 20(a)-(h) below. First, herd dynamics are influenced by the relative change in prices induced by the outbreak. Initially, there is a small surge in distress sales, but with resulting market closures, there are incentives to hold animals (panels a and b), causing herd populations to rise. Depressed sales cause prices to spike in the meat market, which are exacerbated when distress sales occur over a short period of time (panels c through e). At the same time, differences in the time in which distress sales take place have no appreciable impact on the evolution of disease (panels f and g). However, scenario 4, in which 40% of markets are closed, considerably amplifies these affects, particularly on prices, trade, and the number of infected animals, which rises relative to the other scenarios. The rice scenario (scenario 5) has a very modest impact on traded rice and rice prices, causing a slight decline in domestic trade and a slight increase in prices during the initial harvest year in which the outbreak takes place. However, these impacts reverberate over time, as price effects in the year of the outbreak, combined with the fact that the outbreak continues at low levels over subsequent years, amplify these impacts over the remainder of the simulation.

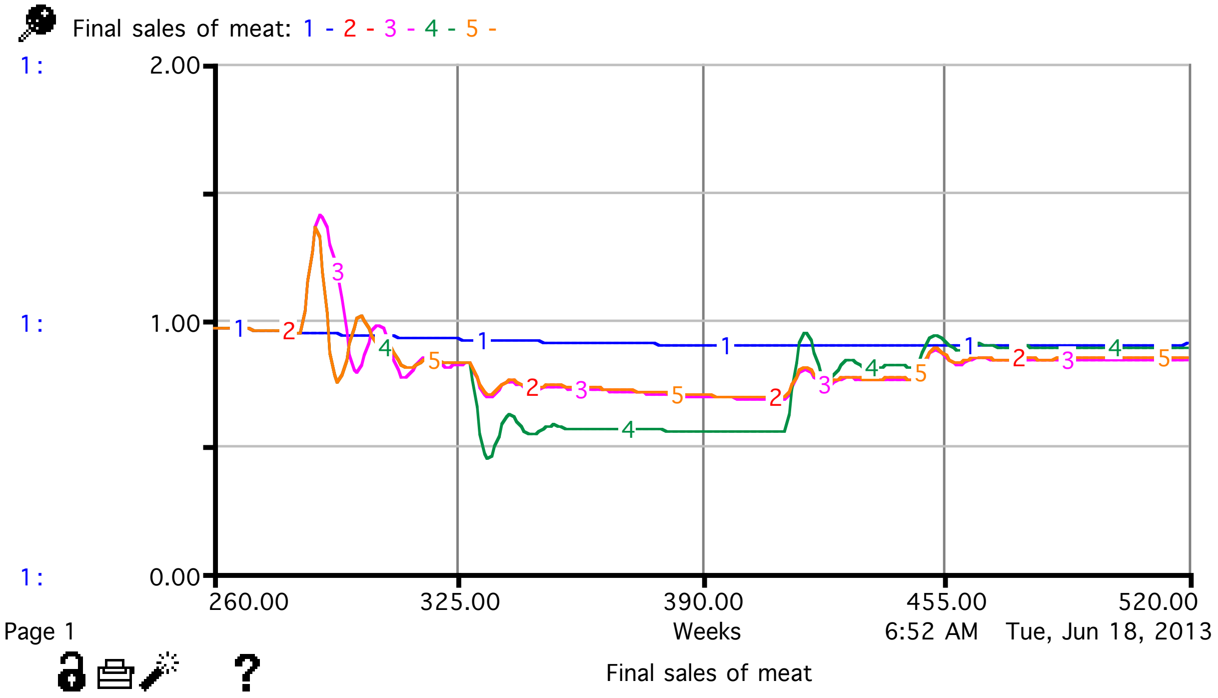
(a) Herd dynamics



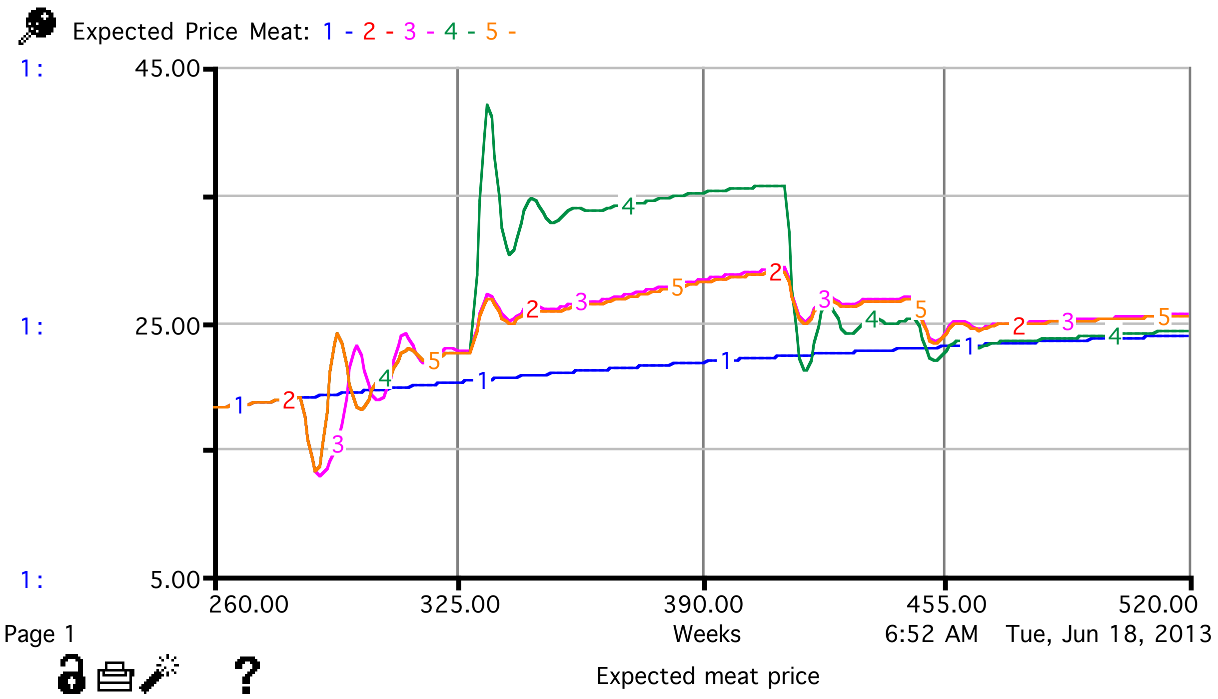
(b) Total animal sales



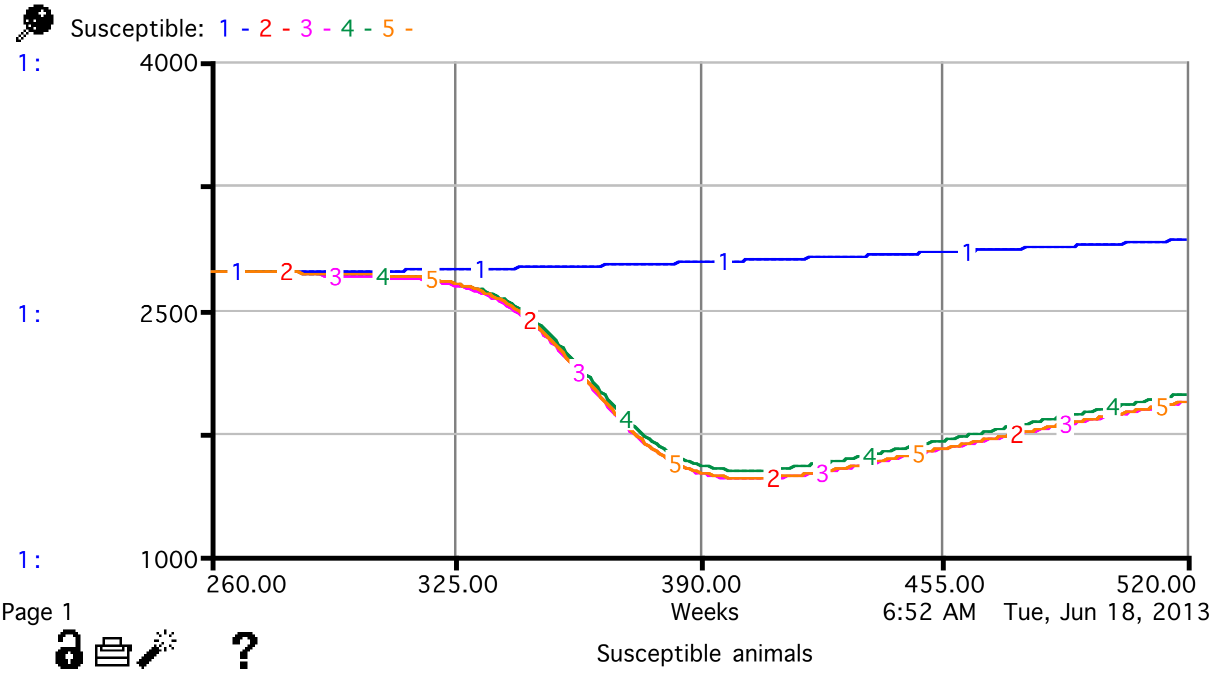
(c) Total meat sales



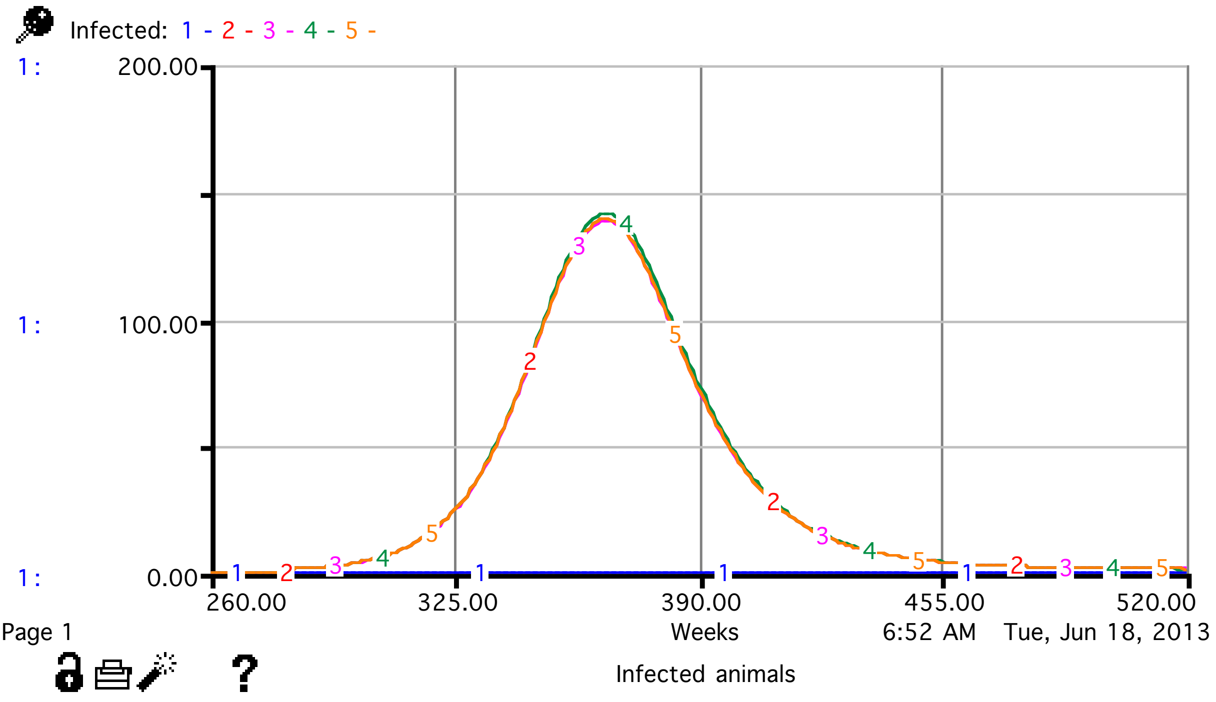
(d) Expected prices of meat



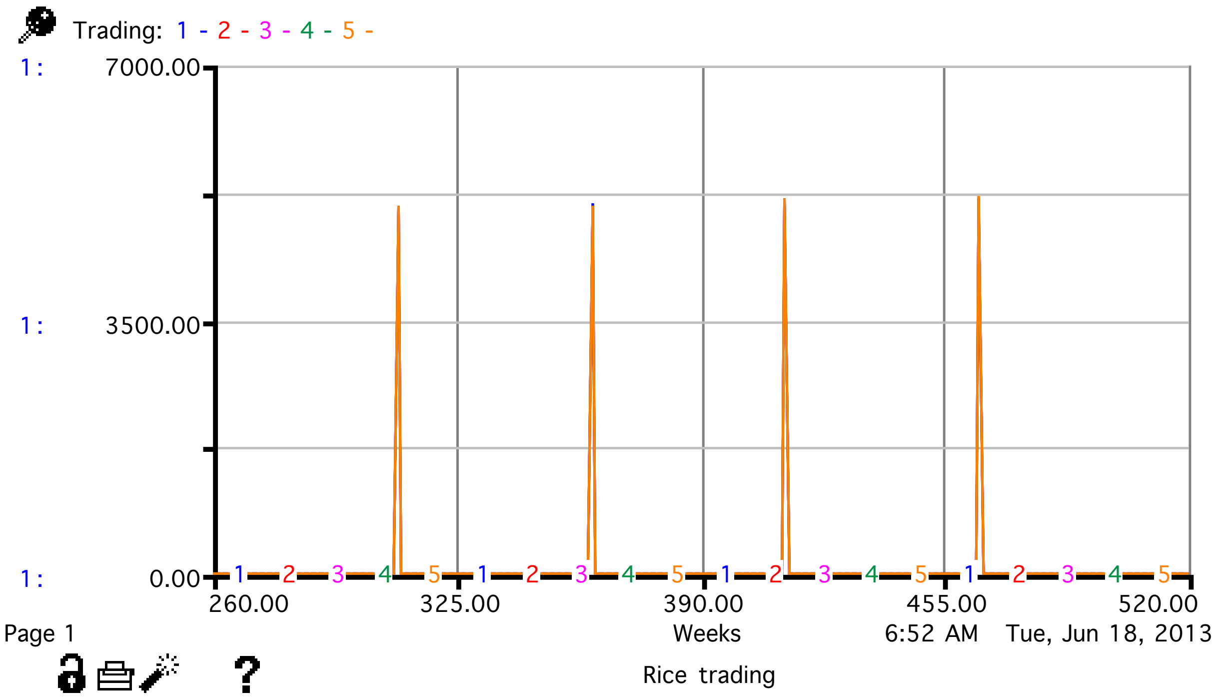
(e) Evolution of susceptible population during the FMD outbreak



(f) Evolution of infected animals during the outbreak



(g) Trading of rice stocks



(h) Evolution of rice price movements

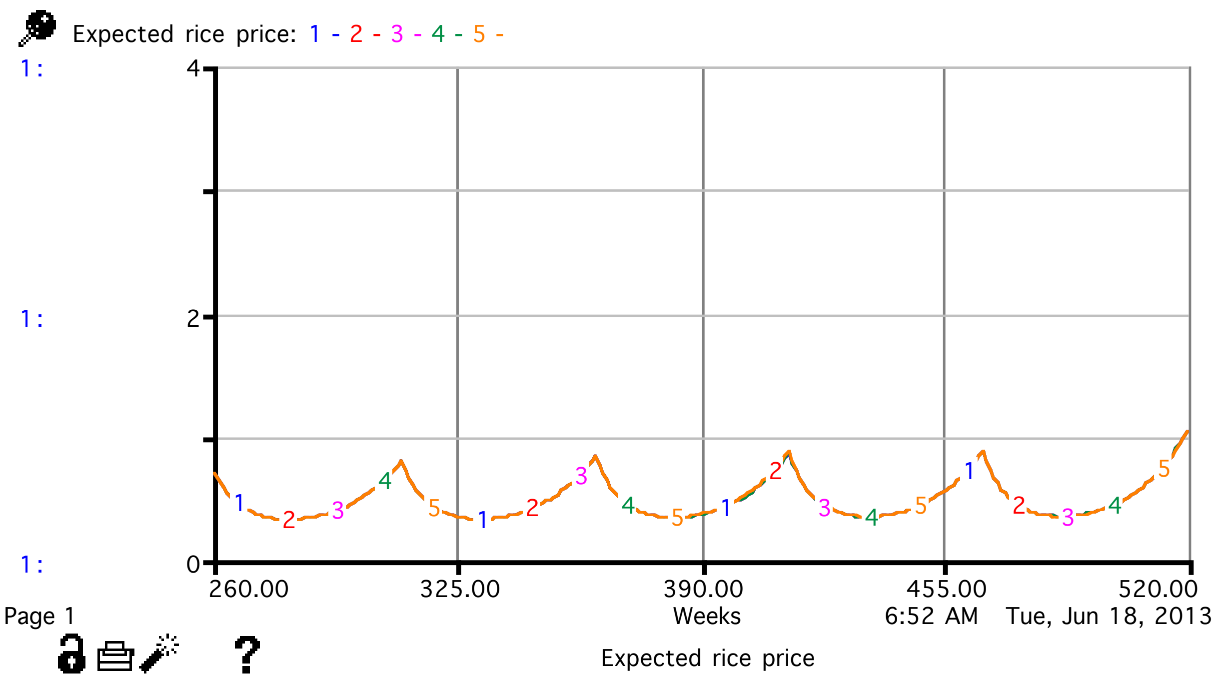


Figure 20: Scenario results – market scenarios

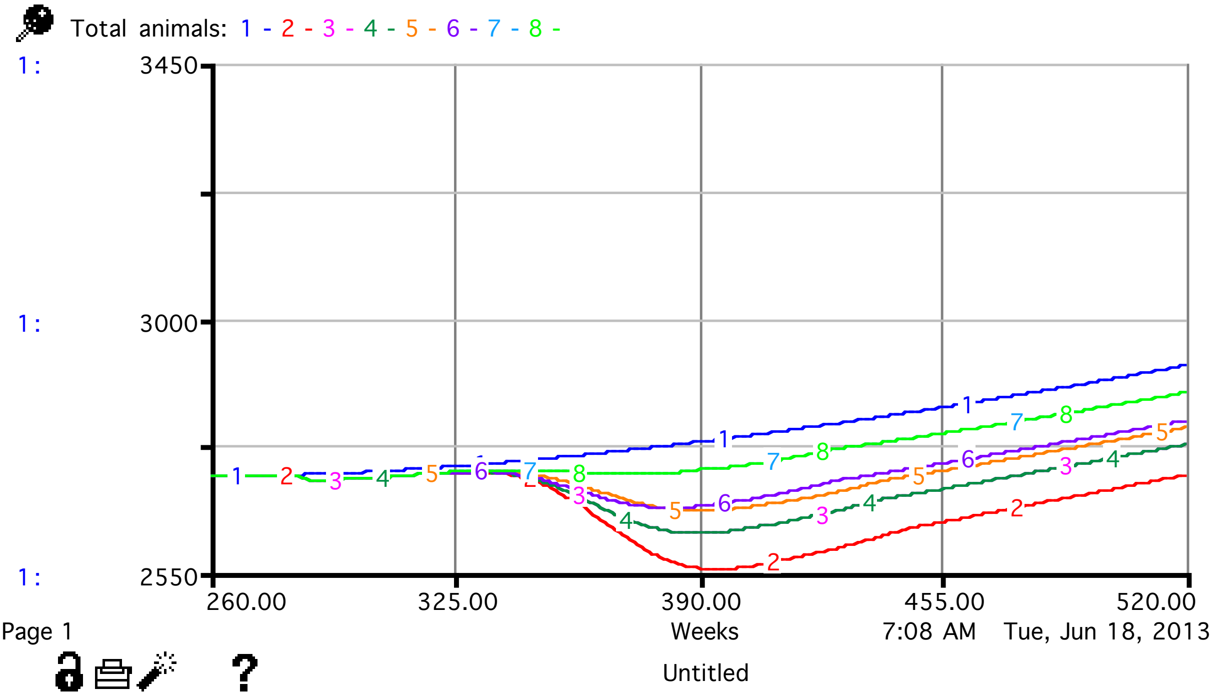
We consider a second set of simulations summarized in table 6 in which we consider the impact of different types of vaccination strategies. We apply these (labeled below as S3V-S8V) to the scenario denoted above as S2. Here, we consider the impact of differences in vaccination capacity, delays in starting vaccination, and the threshold of animals impacted by FMD that induces mobilization of a vaccination campaign. These results are illustrated in figures 21(a)-(h) below.

The results highlight the positive impacts of comprehensive vaccination policies that act quickly and vaccination as many animals as possible. Establishing a low threshold for starting a vaccination campaign (S5V) minimized the impact on market and herd dynamics more than other policies (S3V – standard vaccination and S4V – vaccination with reduced delays in mobilization). However, these need to be traded off against the costs of vaccination and mobilization campaign. While combined vaccination campaigns illustrated in S7V and S8V reduce the severity of disease by one-half (in terms of number of infected animals), the duration of disease is relatively similar in our simulations, suggesting that expensive vaccination strategies may not represent good value.

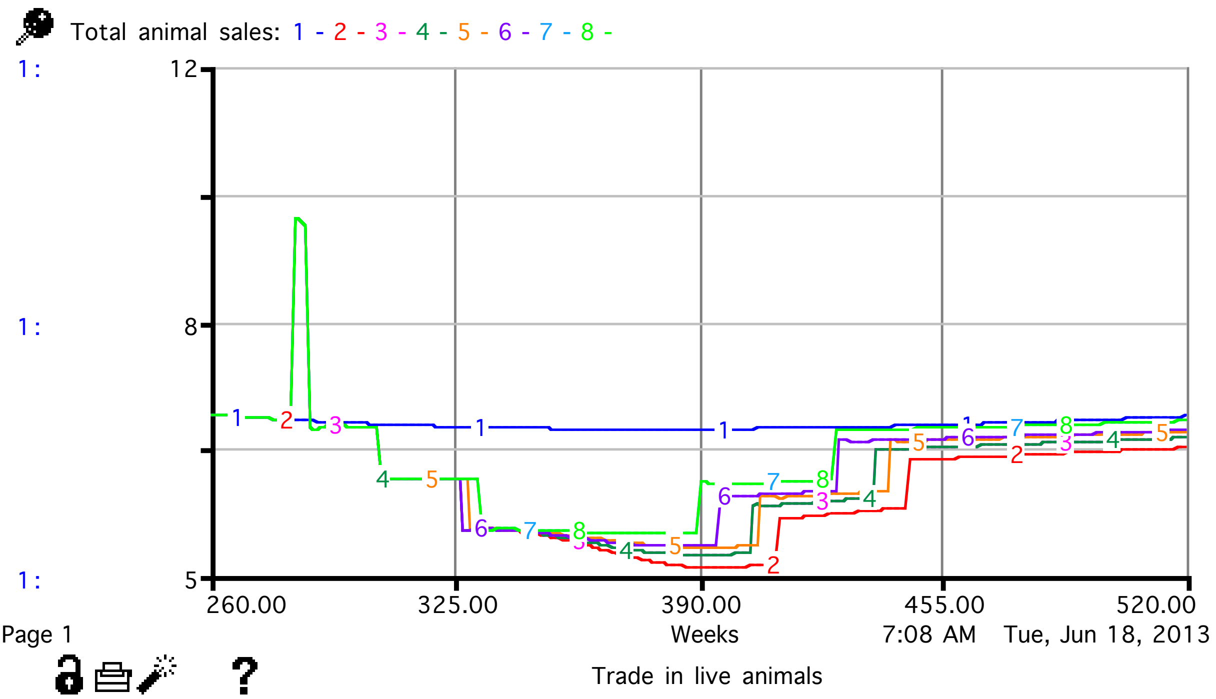
Table 6: Conceptual framework for FMD impact assessment in Cambodia: vaccination policies

	Initial number of animals infected with FMD	Distress sale period	Markets closed	Paddy affected	Vaccination capacity (animals per week)	Delay in vaccination (weeks)	Vaccination threshold (animals)
S1	*Baseline: No FMD outbreak*						
S2	1,000	4 weeks	20%	5%	No vaccination	5	20,000
S3V	1,000	4 weeks	20%	5%	5,000	5	20,000
S4V	1,000	4 weeks	20%	5%	5,000	1	20,000
S5V	1,000	4 weeks	20%	5%	5,000	5	5,000
S6V	1,000	4 weeks	20%	5%	10,000	5	20,000
S7V	1,000	4 weeks	20%	5%	10,000	5	5,000
S8V	1,000	4 weeks	20%	5%	10,000	1	5,000

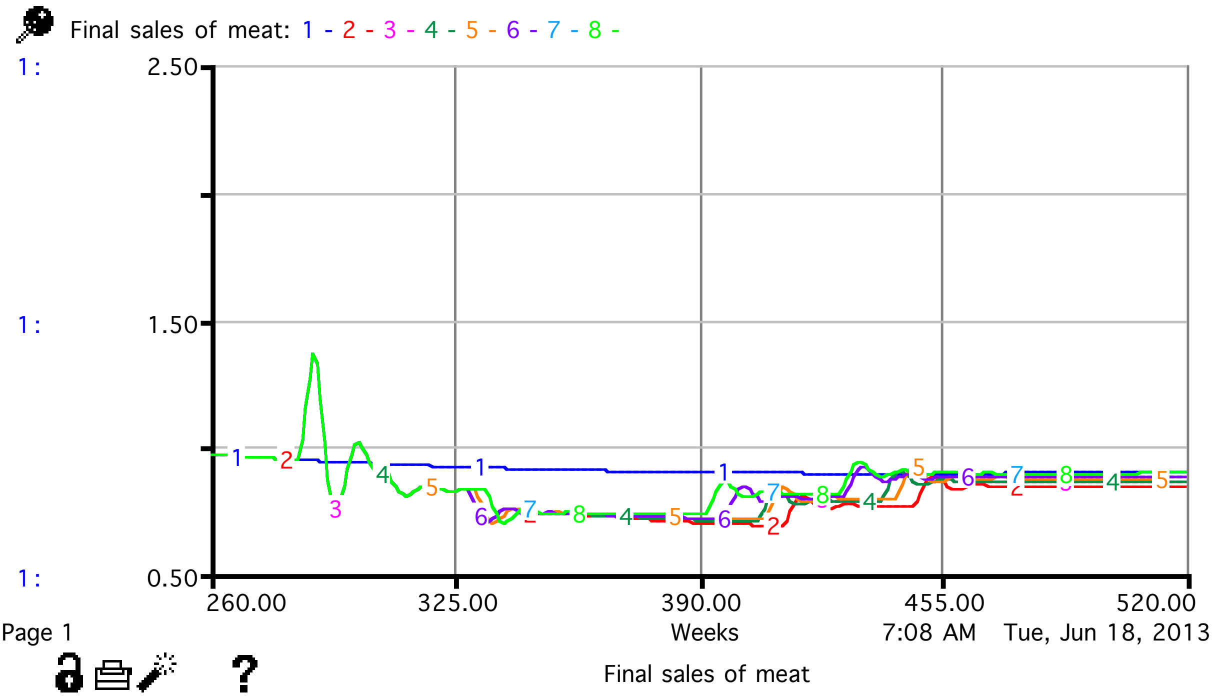
(a) Herd dynamics



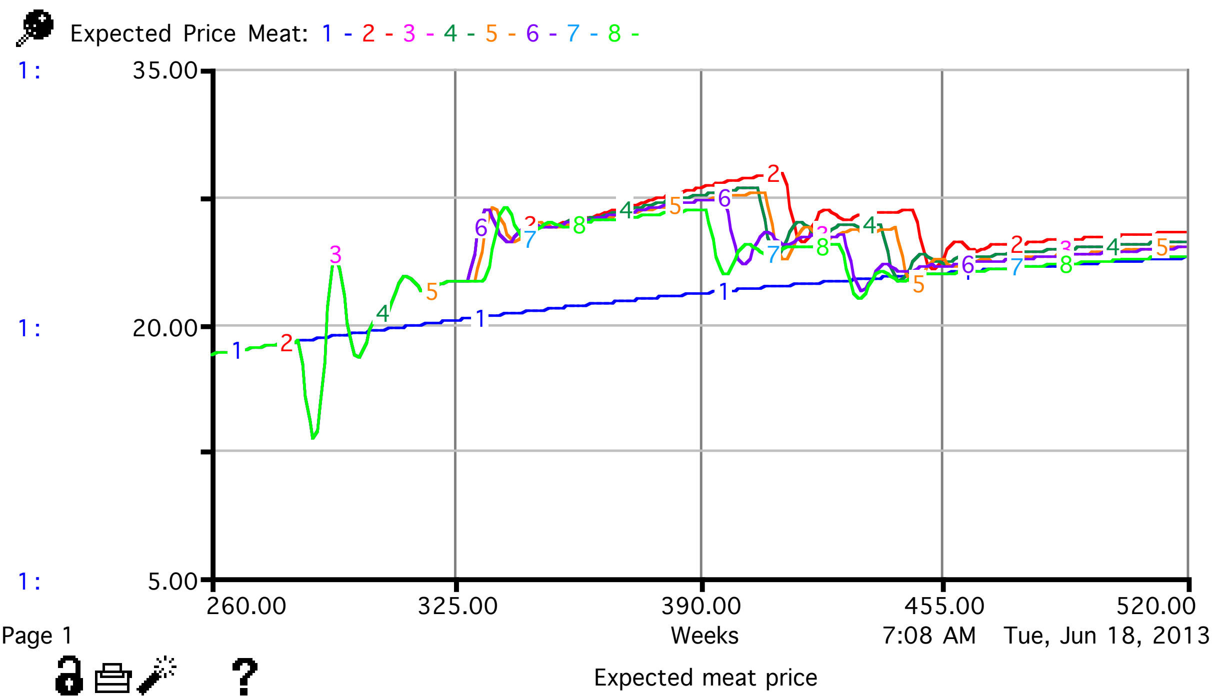
(b) Total animal sales



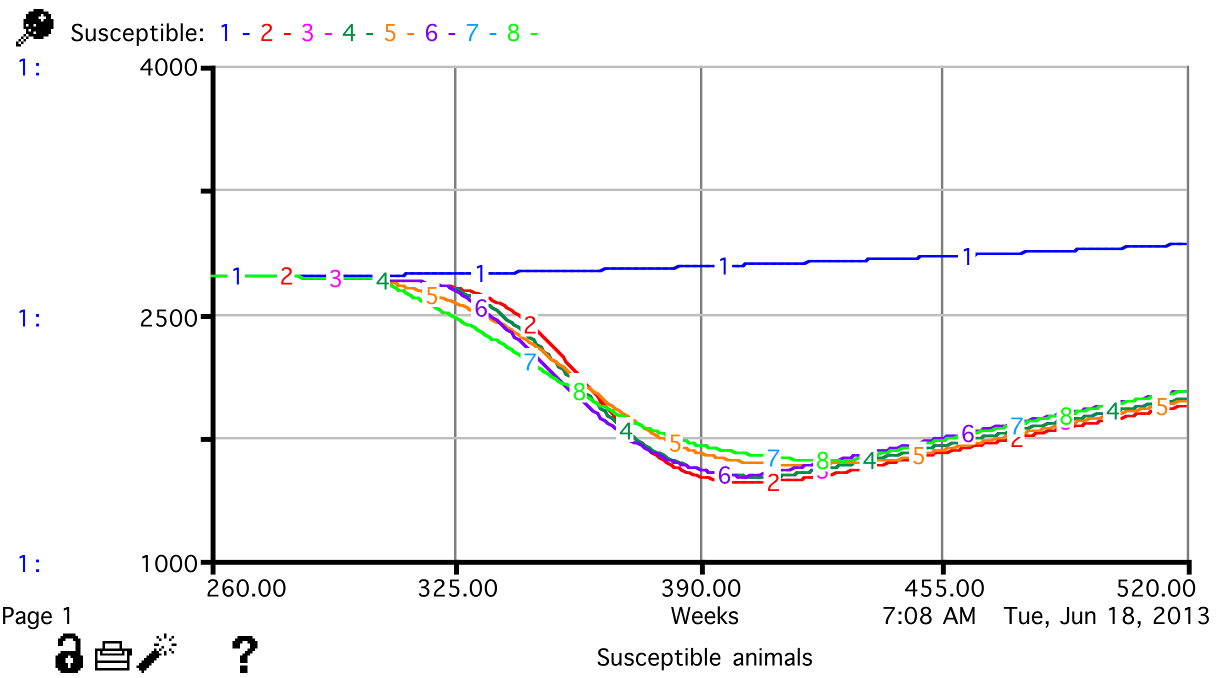
(c) Total meat sales



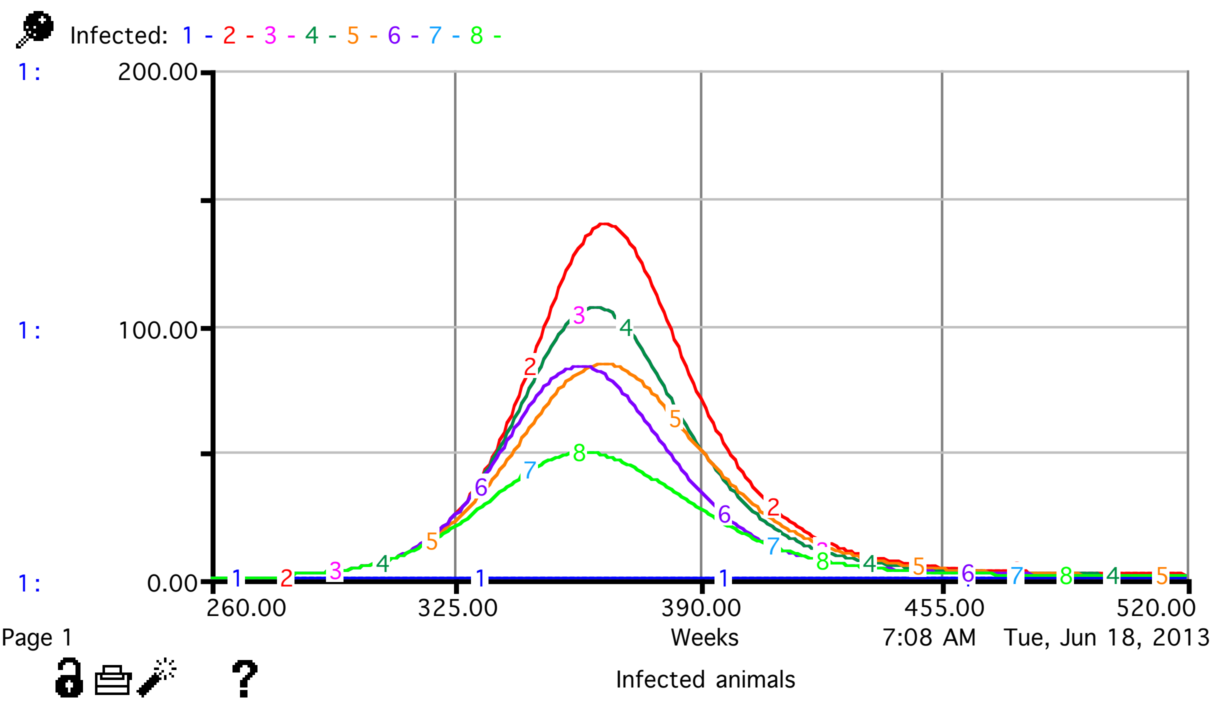
(d) Expected prices of meat



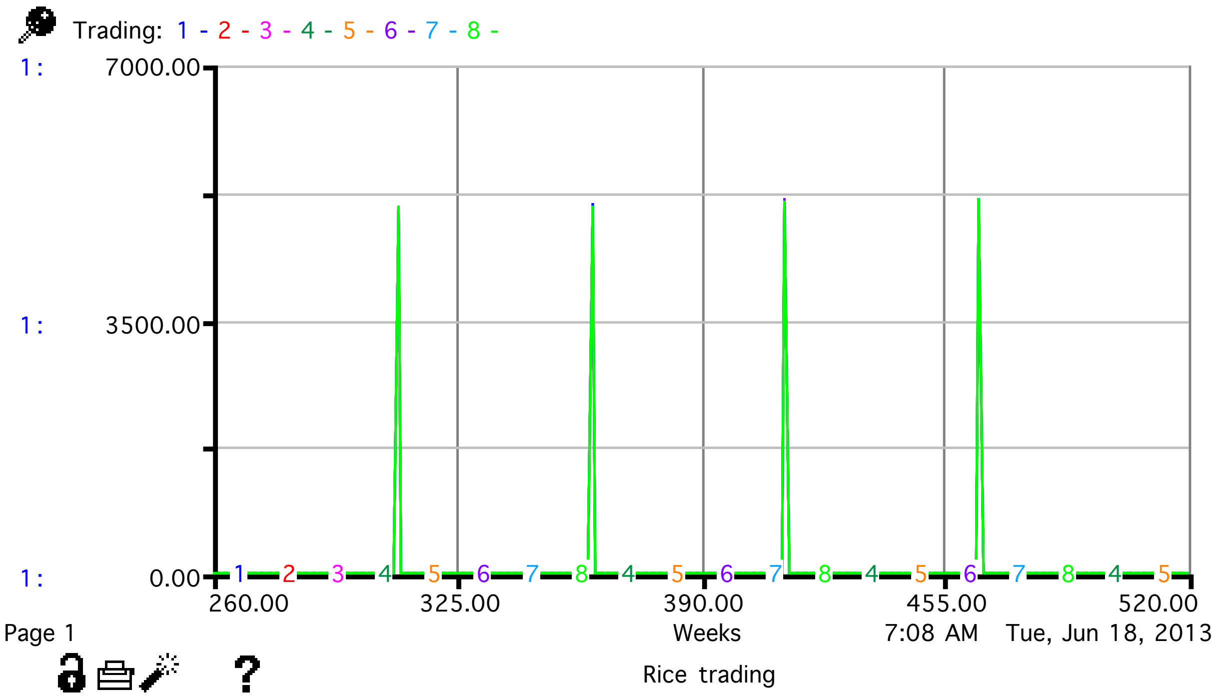
(e) Evolution of susceptible population during the FMD outbreak



(f) Evolution of infected animals during the outbreak



(g) Trading of rice stocks



(h) Evolution of rice price movements

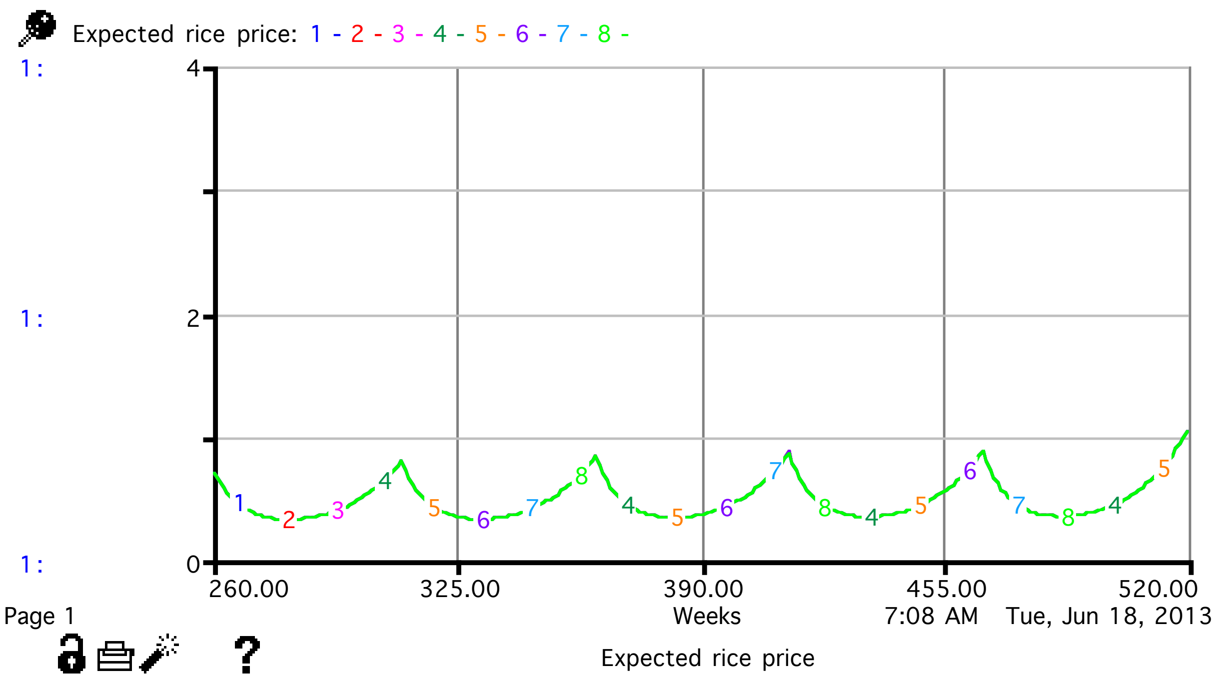


Figure 21: Scenario results – vaccination policies

Table 7 summarizes the financial impacts associated with the different outbreak scenarios relative to the baseline. Counter-intuitively, the net present value of cumulative farm profits in a situation of no disease is lower than in all outbreak scenarios. The intuition behind this is that while revenues fall under a disease outbreak, costs fall by more as farmers maintain (and sell from) smaller herds. As speculated earlier, the additional benefit of more intensified vaccination strategies in terms of farm profits does not compensate for the added costs; indeed, as we do not have estimates for mobilization and resource costs of vaccination programs, we underestimate the full costs of such programs. Of course, this higher level of producer revenue is an aggregate result only – individual producers impacted by the disease are worse off once affected, given the added costs paid by affected producers, while those not affected benefit from higher prices. Consumers, on the other hand, are worse off from the standpoint of consumer surplus under disease situations as they pay higher prices for scarcer meat. Information on other value chain actors was not collected/incorporated here, and is an area for future research.

Table 7: Conceptual framework for FMD impact assessment in Cambodia: summary of financial impacts (net present value in '000 USD)

Scenario	Cumulative farm profits	Vaccination costs	Treatment costs	Mortality costs	Net impact	Consumer surplus
Baseline	712,088	-	-	-	712,088	5,226
S2	811,127	-	32,220	9,619	769,288	5,123
S3	808,975	-	32,101	9,671	767,203	5,123
S4	846,980	-	32,752	12,214	802,015	5,075
S5	811,127	-	32,220	9,619	769,288	5,123
S3V	798,423	725	25,586	7,521	764,592	5,139
S4V	798,423	725	25,586	7,521	764,592	5,139
S5V	793,863	1,164	22,443	6,553	763,702	5,145
S6V	786,225	1,316	20,071	5,811	759,027	5,153
S7V	773,476	2,090	13,996	3,961	753,428	5,168
S8V	773,476	2,090	13,996	3,961	753,428	5,168

Summary

The policy results presented above provide some preliminary insights into the complex interactions associated with animal disease. Animal diseases set into motion behavioral changes on herd marketing and breeding that subsequently impact the evolution of disease and influence patterns of production and marketing in markets that use livestock as an input (e.g., rice). These impacts are generally overlooked in conventional animal health studies, where the focus is primarily on the costs associated with control. At aggregate (national) levels in situations where livestock and products are non-tradable, the impact of a disease arises through a supply shock that increases prices, creating incentives to sell now and reducing cattle inventories in the future. On balance, farmers over our simulation period (five years) benefit from this phenomenon provided they are not directly impacted by disease itself.

A partial assessment of the net benefits of disease incursion versus the costs of different control mitigations suggests *prima facie* that producers are better off under a condition of disease. However, we caution that we have not considered the full range of costs associated with disease, including opportunity costs of producers or government. Moreover, as FMD costs are often localized, patterns of local movements matter suggesting significant regional implications and impacts that our baseline model does not consider. A worthwhile extension of this model would be to disaggregate this into regions and to account for disease spread over space (see Rich 2008 for an example of how to do this in an SD setting).

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Annexes

Annex 1: FAO Protocol for Impact Assessment

The FAO has an established institutional set of protocols for impact assessment of the kind represented by SPADA. This includes a basic rationale and criteria for direct and indirect impact evaluation. Here we briefly summarize these components.

Scope of Economic Analysis

- Determine whether a proposed strategy is viable in economic terms, i.e. do the expected benefits exceed the expected costs?
- Identify from what sources it might be financed. Those who benefit most might reasonably be expected to contribute most. However, the method of contribution (e.g. payment at point of service, direct or indirect taxation) needs to be designed to make financing efficient.
- Identify potential risks of non compliance. Those who do not expect to benefit or find it hard to pay for new biosecurity measures may be less inclined to comply with regulations.

Economic Benefits of Control Strategies

- Determine whether a proposed strategy is viable in economic terms.
    - Do the expected benefits exceed the expected costs?
- Identify from what sources it might be financed.
    - Those who benefit most might reasonably be expected to contribute most. However, the method of contribution (e.g. payment at point of service, direct or indirect taxation) needs to be designed to make financing efficient.
- Identify potential risks of non compliance.
    - Those who do not expect to benefit or find it hard to pay for new biosecurity measures may be less inclined to comply with regulations.

Economic Costs of Control Strategies

- The total cost of a policy.
    - This is the cost of the extra resources used to implement it plus the total loss in output value that it creates.
- The costs incurred by each major stakeholder.
    - Some of these will be actual costs (new resources used) and some will be transfer costs. (For example, compensation does not represent a real cost – no resources are used up – but finances are transferred from the government to farmers to reduce the impact of their loss.)

Direct Costs

- Investment needed to achieve and maintain a heightened state of bio-security.
  - strengthening of veterinary services infrastructure and capacity
  - improved or new farm buildings and infrastructure, equipment, staff and training
  - improved facilities at markets
  - in extreme cases, complete relocation of farms or markets
- Recurrent costs of preventing outbreaks.
  - surveillance and diagnosis costs
  - movement control
  - administrative costs of enforcing regulations
  - on-farm bio-security measures
  - on-farm traceability measures
  - in some cases vaccination

Other Costs

- Indirect costs
  - These are the costs resulting from reduced levels or values of production because of temporary or permanent changes to management systems or markets. In practice, when calculations are made with simulation models, the indirect costs are usually captured for in the estimation of benefits.
- Transfer costs
  - Costs transferred from one stakeholder to another
- Compensation
  - To encourage compliance with culling regulations.
  - To avert a livelihoods crisis.