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FAO ANIMAL PRODUCTION AND HEALTH



working paper

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Methodological issues and applications to rinderpest control programmes in Chad and India

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Contents

FIGURES

Preface

Around 2.6 billion people in the developing world are estimated to have to make a living on less than US$2 a day and of these, about 1.4 billion are 'extremely' poor; surviving on less than US$1.25 a day. Nearly three quarters of the extremely poor – that is around 1 billion people – live in rural areas and, despite growing urbanization, more than half of the 'dollar-poor' will reside in rural areas until about 2035. Most rural households depend on agriculture as part of their livelihood and livestock commonly form an integral part of their production system. On the other hand, to a large extent driven by increasing per capita incomes, the livestock sector has become one of the fastest developing agricultural sub-sectors, exerting substantial pressure on natural resources as well as on traditional production (and marketing) practices.

In the face of these opposing forces, guiding livestock sector development on a pathway that balances the interests of low and high income households and regions as well as the interest of current and future generations poses a tremendous challenge to policymakers and development practioners. Furthermore, technologies are rapidly changing while at the same time countries are engaging in institutional 'experiments' through planned and un-planned restructuring of their livestock and related industries, making it difficult for anyone to keep abreast with current realities.

This 'Working Paper' Series pulls together into a single series different strands of work on the wide range of topics covered by the Animal Production and Health Division with the aim of providing 'fresh' information on developments in various regions of the globe, some of which is hoped may contribute to foster sustainable and equitable livestock sector development.

Executive Summary

Animal diseases impose a variety of direct and indirect impacts on an economy, many of which are neither well-understood nor well-analyzed. Various methods exist to evaluate economic impacts, but many of these focus only on specific aspects of or a subset of stakeholders affected by disease and not the totality of impacts throughout the economy. Such considerations are important in the *ex-post* evaluation of disease in order to assess the relative magnitude of "how effective" a particular mitigation (or set of mitigations) has been.

Rinderpest was once one of the world's most feared diseases of livestock. It mainly affects cattle species, with the most virulent strains killing up to 95 percent of infected animals when introduced into naïve populations (Roeder and Rich, 2009). Concerted international campaigns have now eradicated the disease globally. However, a major gap in the story of rinderpest eradication has been a comprehensive assessment of the socio-economic impacts of its control and eradication. While much has been documented on the epidemiological, technical, and institutional lessons resulting from rinderpest control and prevention, little has been written on what this means for society at local, national, regional and global level. Instead, what exists at present are fragmented national and international analyses, which use disparate and sometimes *ad hoc* methodologies, and do not get at the "big picture". These research gaps necessitate a unifying framework that can bridge and synthesize the lessons from the past in the context of rinderpest and which can be applied in the analysis of future control and eradication campaigns.

This paper offers a more rigorous methodological approach to estimating the global impact of rinderpest eradication. An important contribution is in highlighting the different levels of impacts and benefits associated with different groups of stakeholders. The method is applied at a national setting an combined with variety of standard economic tools for impact assessment to estimate the impacts of rinderpest eradication in two case studies – Chad and India – at the producer, sector, national, and regional levels. The analysis suggests benefits to rinderpest eradication in both countries, though these are sensitive to the parameter assumptions made, particularly the mortality rate associated with rinderpest.

For Chad, at a sector-level, by extrapolating the benefits associated with rinderpest control through its effects on herd demographics, we estimate that the benefit-cost ratio for the totality of control programmes (JP-15, PARC, and PACE) over the period 1963-2002 was just over 4, which takes into account sector-level benefits and exclude macroeconomic and regional ones attributed to the programmme. Applying livestock sector multipliers that range between 3.5-4 yield much higher aggregate benefits to the various eradication programmmes. Analyses utilizing social accounting matrices (SAMs) and computable general equilibrium (CGE) models yield additional insights. For instance, in the year 2000 (the base year for the available SAM for Chad), SAM multiplier analysis reveals that GDP would have been about 1 percent lower relative to a "no-eradication" scenario. If we look at household-level shocks from the SAM, we find that rural households, the most vulnerable group to outbreak of rinderpest, would have had incomes 2.6 percent lower in the absence of rinderpest control. When we decompose these results further, we find that shocks to livestock supply are modulated through manufacturing activities, suggesting that such groups have more complex interactions within the value chain than one might first conceive. This suggests that rural households diversify into a variety of activities, such that the total benefits of rinderpest eradication will have a variety of non-livestock related benefits as well.

In India, the benefits to rinderpest eradication are positive, but highly dependent on the time period considered. The analysis considered an assessment of the 1972-1989 mass vaccination programme versus scenarios of limited vaccination (i.e., vaccination rates from the late 1950s) and no control (i.e., as practiced in the 1930s), as well as an analysis of the final eradication programme in the 1990s that led to the eventual eradication of the disease. In the former case, the benefit-cost ratio of mass vaccination vis-à-vis limited vaccination was just less than 1 (0.98), though this does not consider the multiplier impacts on other, non-livestock parts of the economy. When compared to a scenario of no-control, the benefit-cost ratio is much higher (estimated at 5.42), though this strongly depends on the assumed mortality rate associated with rinderpest. On the other hand, the final eradication of rinderpest in the 1990s under the NPRE was a huge success from the standpoint of its BCR (well over 60), fueled by much higher market access for livestock exports that boomed as rinderpest freedom was achieved.

Introduction

Animal diseases are responsible for a host of economic impacts manifesting themselves through a variety of pathways: disease induced production and productivity losses, direct and indirect expenses associated with their control, generic 'depression' of domestic economic activity, specific disruptions of domestic and international commerce, as well as, in some cases, human health effects. These disruptions can be specific to the livestock sector itself, as well as in related downstream industries (e.g., processing, distribution, retail), but can also affect 'non-livestock sectors' such as services or tourism (e.g. when wildlife are affected). While the depth of commercial impacts of animal diseases rests on the degree of trade and commercialization associated with both a particular production system and international regulations governing such trade, animal disease impacts extend into the human health sector in case of zoonotic diseases such as avian influenza or Rift Valley Fever (RVF). At the same time, livelihoods impacts are paramount in many contexts, because the success or failure of disease control programmes is intimately related to support and compliance offered by livestock keepers. This aspect is particularly relevant in the developing world where livestock serve important non-commercial roles (e.g. insurance, savings) and are for many households an important pathway out of poverty (Rich and Perry, 2010).

Rinderpest was once one of the world's most feared diseases of livestock. It mainly affects cattle species, with the most virulent strains killing up to 95 percent of infected animals when introduced into naïve populations (Roeder and Rich, 2009). Rinderpest was eliminated from Western Europe by the beginning of the 20th century, never established itself in Australia and South America despite occasional introduction, but remained endemic in sub-Saharan Africa and Asia. Major pandemics in Africa, the last in the early 1980s, caused particular devastation to the pastoral areas of Western and Eastern Africa. However, concerted international eradication campaigns successively building on advances in control practices (see Roeder and Rich, 2009 for a review) eradicated the disease globally, with a pronouncement made in October 2010 that field activities would end, and an official pronouncement of its eradication to be made by the Food and Agriculture Organization (FAO) and the World Animal Health Organization (OIE) in May 2011, marking the end of rinderpest on earth.

A major lacuna in the history of rinderpest concerns the socio-economic impacts of its control and eradication. Much has been documented on the epidemiological, technical, and institutional lessons resulting from rinderpest control and prevention, but very little has been written on what this means for society at local, national, regional and global levels. Various estimates of costs and benefits of rinderpest eradication have been suggested: Normile (2008) cites FAO estimates of control costs of US$610 million and potential annual benefits for Africa alone at US$1 billion. Catley (2005) cites FAO estimates that the benefits of rinderpest control on livestock production in India from 1965-1998 were US$289 billion, while for Africa during the same period they were US$47 billion. However, most of these estimates are given without a more detailed discussion of how they were derived, nor are standard methodologies applied or cited in their calculation. Furthermore, many of the impacts in terms of international trade, downstream sectors, or unrelated ('non-livestock') sectors are likely not fully captured, nor are more nuanced impacts on behaviour, the environment, and potential unintended consequences resulting from rinderpest eradication.

This paper offers a more rigorous methodological approach to estimating the global impact of rinderpest eradication that highlights the different levels of impacts and benefits associated with different groups of stakeholders. We begin with a review of the (limited) state of knowledge of the economic impacts of rinderpest eradication. The paper then presents additional impact assessment considerations and provides a description of tools and methods that could be applied at different levels of analysis. We then apply the proposed assessment methodology to estimating the impact of rinderpest eradication for two case studies: Chad and India. A discussion of future applications is further provided. While this case study application cannot give a comprehensive global perspective on the disease eradication, it demonstrates how to conduct similar ex-post analyses and indicates how to structure data collection efforts for future economic assessments of disease control campaigns.

Current state of knowledge: what is known about the socio-economic impact of rinderpest and its control/eradication?

Much of the current state of knowledge on the socio-economic impacts of rinderpest eradication has been summarized in Roeder and Rich (2009), and this section will draw heavily from that analysis. These authors note among other things that much of the existing knowledge base on the economic impact of rinderpest is case-specific and Africa-focused. The most widely cited recent study in this area was conducted by Tambi *et al.* (1999) in the context of the Pan-African Rinderpest Campaign (PARC). Their study reports on benefit-cost analyses for a sub-set of 10 of the 35 PARC countries: Benin, Burkina Faso, Cote d'Ivoire, Ethiopia, Ghana, Kenya, Mali, Senegal, Tanzania, and Uganda. The total costs of the control programme in these 10 countries, estimated at €51.6 million, were assessed against benefits in terms of estimated disease avoidance, taking account of impacts rinderpest control would have on cattle production and downstream production of meat, milk, hides, and animal traction. These costs and benefits were assessed at a national level, with benefit-cost ratios (BCRs) calculated for each country.

The study estimated the total value of avoided losses to be € 99.2 million over 1989/90-1996/97, in terms of the improvements induced by higher productivity in livestock and increases in livestock-derived products. Impacts on international trade or other sectors were not assessed, so the benefits reported in this study are likely an underestimate. At a sample level, the BCR for the PARC programme was 1.85, ranging from 1.06 in Cote d'Ivoire to 3.84 in Tanzania. These authors also conducted an economic welfare analysis using basic producer and consumer surplus techniques, with representative supply and demand elasticities, to assess producer and consumer gains. On average, most (81 percent) of the welfare gains (estimated at €57.5 million) went to producers, with the majority (92 percent) of these benefiting meat producers over other segments of the value chain.

The Tambi *et al.* (1999) study provides a starting point for a more comprehensive assessment of rinderpest control, though it is somewhat limited in the scope of analysis. As noted earlier, the benefits accounted for are limited to only a few sectors in the livestock economy, omitting consideration of important second-round impacts that could be quite large. Indeed, the multiplier analysis of Roeder and Rich (2009) found broader macro-economic impacts of each US$1 invested in the cattle sector in East Africa yielded a US$3-5 increase in overall economic activity. Nor are these impacts traced out dynamically to assess the long-run impacts of rinderpest control. More subtly, the welfare analysis conducted by Tambi *et al.* (1999) does not capture dynamic and intersectoral linkages that could be quite important.[1]

[1] This is a rather pedantic point, but the Tambi study does not utilize appropriate means of computing producer and consumer surplus in a multi-market setting. Briefly, an appropriate path of integration that traces the causality of impacts from one sector on downstream sectors needs to be defined to theoretically justify the approach; see Just et al. (2004), chapters 4 and 9.

A more traditional benefit-cost analysis, lacking the economic sophistication of the Tambi *et al.* (1999) study but equally comprehensive at the production level, is that of Felton and Ellis (1978), which evaluated the JP-15 programme in Nigeria. As with the Tambi study, detailed information on costs related to the disease campaign were gathered and compared to the benefits of control in terms of outbreaks avoided. Unlike Tambi *et al.* (1999), only benefits from avoided mortality and impaired reproduction were considered; impacts on increased milk yield and growth rates were not included. The authors examined different scenarios related to outbreak size and improved reproduction engendered from disease control. Their analysis found that the net benefits to JP-15 in Nigeria over a ten-year period were £785,127, and when compared to the costs of the programme yielded a BCR of 2.48. At higher levels of benefits (i.e., from greater improvement of reproductive performance over 10 years and higher benefits from mortality avoided over a 50 year time period), BCRs of over 5 were computed.

Two important, and often overlooked, components can be found in the analysis of Felton and Ellis, although neither is fully assessed. First, the authors make an important point about cattle population trends in the context of rinderpest, in terms of the age structure of livestock herds. In particular, they note that an important consequence of rinderpest epidemics is that herders will keep a larger number of older cows in their herds, over and beyond what is efficient from a productive stock standpoint. The rationale is that older cows serve an insurance role in case of rinderpest outbreaks. The authors note that female slaughter rates increased from 1968 onwards in response to improved control of the disease. This is a potentially important behavioural change induced by rinderpest control that has generally been overlooked as a benefit, both to producers and consumers. At the same time, the authors only discuss this as a possible effect, without associating any cost/benefit with it.

Second, Felton and Ellis discuss the issue of carrying capacity for livestock populations. In their analysis, they made some projections about the carrying capacity of different types of land (with and without clearance of tsetse flies) and note the potential limits that the natural environment may exert on further expansion of livestock populations. Again, these are not assessed in their benefit-cost analysis, but production figures from FAO over the past 40 years suggest the possibility of some carrying capacity limitations on livestock population, as growth in Nigeria from the 1990s has flattened somewhat.

Other assessments of the socio-economic impacts of rinderpest control or the losses associated with it are relatively piecemeal. Blakeway (1995) computed a rather large BCR of 34 in his evaluation of the benefits of rinderpest control in South Sudan, contrasting the US$200 000 in control costs with the benefits in terms of avoided losses in livestock deaths (US$3.8 million) and avoided value of food aid dependence (US$3 million). Nawathe and Lamorde (1984) calculate the losses from the 1983 rinderpest outbreak in Nigeria at US$2 billion, based on mortality across different age cohorts, infection losses (e.g., abortions, morbidity), added surveillance expenditures, lost working hours, and herd replacement costs. Chuta (1990) estimates that late application of the tissue culture rinderpest vaccine during the 1983 rinderpest epidemic reduced net revenue in the cattle sector by 95 to 123 million Naira (US$126-166 million), roughly 5 percent of the value of beef sector output. Matin and Rafi (2006) noted the trade impacts that rinderpest had on Pakistan's access to international beef markets. Roeder and Rich (2009) estimated that the bulk of the increase in beef exports from Pakistan (from less than 1 000 tons before 2003 to nearly 3 000 tons in 2006) was due to Pakistan's declared status as being provisionally free from rinderpest from 2003 onwards. In value terms, Pakistan's beef exports increased by nearly US$3.5 million from 2003-2006 (Roeder and Rich, 2009).

Omiti and Irungu (2010) recently evaluated the benefits and costs of rinderpest eradication in Kenya and Ethiopia, comparing the benefits from increased domestic production and exports against the costs of control campaigns. The authors found that the total benefit associated with rinderpest control in Kenya was US$951 million, of which 44 percent was attributable to higher milk production. In Ethiopia, benefits were estimated at US$434 million, of which 65 percent came from increased production of beef. From a macroeconomic standpoint, rinderpest control was estimated to have increased GDP by 2.4 percent in Ethiopia and 0.5 percent in Kenya. Internal rates of return (IRRs) were generally higher than alternative risk-free investments (e.g., compared to bank deposit or Treasury bills), although the IRR of PACE in Ethiopia (2.6 percent) was lower than the 3 percent alternative baseline rate. In Kenya, IRRs for PARC of about 12 percent were only slightly above those of government Treasury bills (7.4 percent).

The above description highlights the very limited scope of information that is available on the benefits and costs of rinderpest control. In particular, specific details on the benefits side are clearly lacking, as are the application of more generalizable framework to assess the range of benefits that are likely to accrue from rinderpest control and eradication. In the next section, we provide some insights on how to more completely and precisely estimate the potential benefits from rinderpest control, with an eye towards identifying specific measurement metrics and methods.

Knowledge resources for animal disease impact assessments

In this section, we trace out in more detail the general characteristics and dimensions of the socio-economic impacts of animal diseases. A particular focus will be on analytical frameworks that can accommodate these economic effects, with the discussion in the next section focusing on specific methods of analysis.

OVERVIEW OF DISEASE IMPACTS AND RELEVANCE IN THE CONTEXT OF RINDERPEST

Rich and Perry (2010) distil the impacts of animal diseases along five dimensions of impact based on the characteristics of the disease and its setting: disease characteristics, production characteristics, market characteristics, livelihoods characteristics, and control characteristics. Such dimensions of disease impacts themselves take place at 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; (5) indirect impacts at the national level based on local externalities such as effects on the environment, wildlife, and (for zoonotic diseases) human health; and (6) indirect impacts at the global or sub-regional level based on externality effects i.e., savings other countries receive because they no longer have to worry about disease incursion. In all of the above, the 'cost of a disease' is the sum of reduced economic activity/returns and control expenditures. While the latter can be valued directly in terms of the cash costs associated with the control of disease, costs related the former can also result from 'adaptive behaviour' such as keeping an excess of old female cattle as a risk mitigation strategy, for example.

Table 1 summarizes these in the specific context of rinderpest, following the framework of Rich and Perry (2010), and which is further synthesized in Figure 1. First, disease characteristics refer to the epidemiology of the disease and its biological impacts in terms of severity, spread, and endemicity. In the case of rinderpest, impacts were particularly severe from the standpoint of animal mortality, with rapid spread across space (both nationally and internationally) fuelled by animal movements. Indirectly, such impacts further have an effect on the cattle sector in terms of their influence on herd demographics, placing greater importance on risk management than enhancing productive efficiency. Production characteristics refer to how impacts might differ depending on the production systems affected by a disease. In Africa, rinderpest took place primarily in extensive production systems affecting large ruminants, with impacts including direct impacts on livestock producers and downstream industries such as meat, milk, manure, and hides, and indirect impacts on crop sectors through the use of livestock in animal traction. Likewise in Asia, cattle play an important role in terms of animal traction, with rinderpest having potential impacts on other agricultural crop sectors that rely on such draught labor

Table 1. The impacts of animal diseases based on different dimensions and characteristics of impact: applications to rinderpest

Dimension of impact	Characteristics in the context of rinderpest by level of analysis					
	Level 1: Farm	**Level 2: Cattle sector**	**Level 3: Livestock sector**	**Level 4: Value-chain**	**Level 5: Indirect impacts (national)**	**Level 6: Indirect impacts (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					

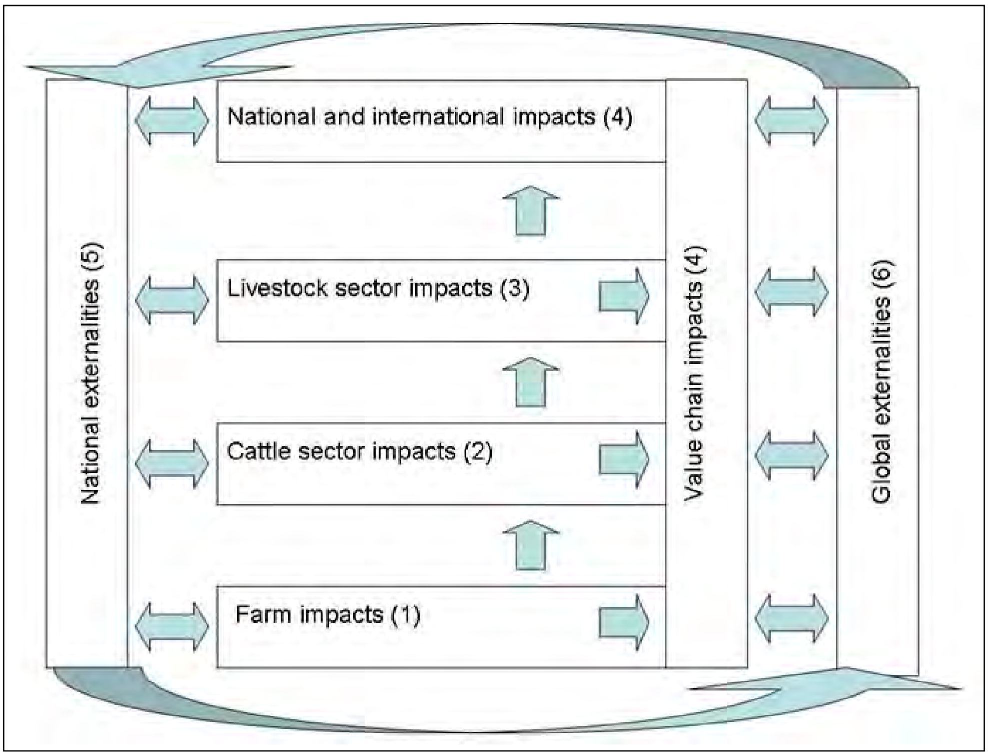
cont.

Table 1. *cont.d*

Dimension of impact	Characteristics in the context of rinderpest by level of analysis					
	Level 1: Farm	**Level 2: Cattle sector**	**Level 3: Livestock sector**	**Level 4: Value-chain**	**Level 5: Indirect impacts (national)**	**Level 6: Indirect impacts (global)**
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
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: Based on an expansion of Rich and Perry (2011) by the authors.

Figure 1. Different levels of socio-economic impacts associated with control of an animal disease



for production. With the exception of the large pandemics that took place most recently in the 1980s, rinderpest was largely endemic at a local level, e.g. in the Somali-ecosystem of East Africa, with particular regions or zones more affected than others.

Conventional animal disease impact assessment focuses mainly on the disease and production side in measuring benefits of an animal health intervention (i.e., levels 1 and sometimes levels 2-3), with less attention to impacts across downstream markets. Significant market linkage effects can be associated with a disease like this, however, including the degree of commercial and downstream impacts and depending on the value chain context in which a disease takes place. In Africa, rinderpest occurred largely in pastoral settings, where value chains are dispersed over large areas and replete with many informal sector actors and market transactions. The implication is that market impacts associated with rinderpest are potentially quite complex and nuanced, with a multitude of small, low-income informal service providers affected. Indeed, Rich and Wanyoike (2010) found that RVF (which affects production systems similar to rinderpest) propagated a host of impacts on casual workers in slaughterhouses, traders, as well as informal service producers in markets and abattoirs (e.g., cart pushers, scrap sellers, etc.). In other words, impacts at level 4 along the value chain, integrating interactions between the chain and the rest of the economy will be important.

Non-sector impacts are likely related to multiplier impacts in local communities affected by current disease outbreaks. Depressed economic activity related to market closures and decreased commerce will have spillover impacts on a range of local community services, including restaurants to shops and consumer households.

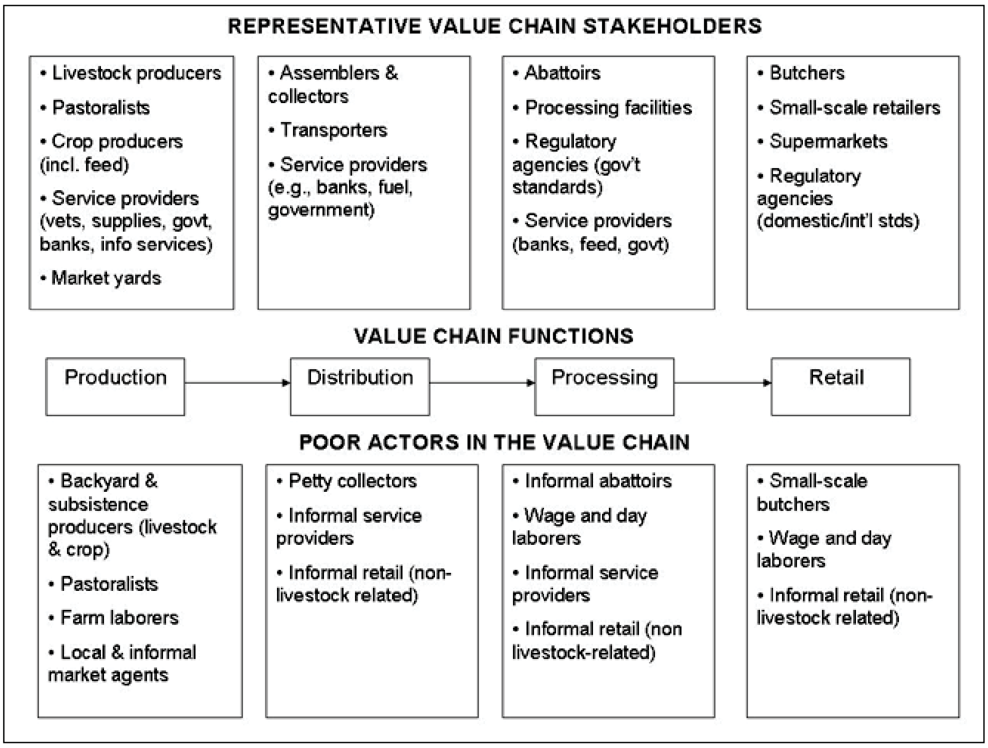
Two other impacts to consider are livelihoods and disease control measures. In the case of rinderpest, livelihood impacts were likely quite high, particularly in pastoral settings where livestock offer a complex array of economic and non-economic services. Measuring control impacts associated with rinderpest is somewhat more straightforward in comparison to other animal diseases. Unlike foot-and-mouth disease (FMD), for example, rinderpest can be controlled effectively with a single injection of a vaccine that confers life-long immunity. Pastoral settings complicate vaccine delivery and sero-surveillance, but innovations such as a heat-stable vaccine developed in the 1990s, participatory epidemiology and the use of community animal health workers (CAHWs) have successfully served to control and monitor rinderpest in high risk areas that are often difficult to access, but serve as reservoirs for disease (Jost *et al.,* 2007). At the same time, there is some evidence that there is an association between rinderpest control and PPR incidence in small ruminants, suggesting some level of externalities as a result of control. In addition, other externalities can be considered, such as greater pressures on feed and water resources by virtue of increased animal productivity, as well as possible externalities associated with wildlife habitats (and subsequent impacts on tourism, particularly in East Africa, for example). There could also be other unintended consequences, such as slower rate of adoption of mechanization for crop production (versus the use of draught animal labour) as a result of rinderpest eradication and control campaigns.

TOOLS AVAILABLE FOR ECONOMIC ASSESSMENTS OF ANIMAL DISEASES AT DIFFERENT LEVELS

Given the many dimensions of impacts observed for animal diseases such as rinderpest, what tools or knowledge resources are at our disposal to measure them? 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. The analysis of Tambi *et al.* (1999) provides an example of how partial equilibrium analyses were used at levels 2 and 3. However, as noted earlier, an important gap in analyses at these levels is incorporating the behavioral responses associated with disease control or eradication. Herd demographics and marketing dynamics could be altered once a disease is successfully controlled, yielding additional benefits over time.

More global analyses at levels 4-6 typically require both more information and/or more sophisticated techniques. For level 4, Rich and Perry (2010) and Rushton *et al.* (2009) point to value chain methodologies as useful for highlighting disease impacts across different sectors and pinpointing potential hotspots for disease risk. Figure 2 provides a schematic view of a representative value chain, including the stakeholders that could be affected by an animal disease outbreak. As such, value chain analyses can elucidate and integrate specific livelihood impacts that other approaches fail to capture. Moreover, value chain analysis goes beyond mapping interactions and stakeholders from production to consumption to assessing the institutional contexts governing the organization of the chain. In particular, an important component of value chain analysis addresses relationships within the chain among different actors, analyzing how such relationships can influence behaviour and incentives for disease control. Such a framework thus moves beyond the typical

Figure 2. Stakeholders and potential poverty impacts in a livestock value chain



top-down impact assessments by revealing the decision environment and actors the decision-making at each stage from "farm to fork." This provides more insight and entry points where disease control measures could be targeted. Perhaps the greatest advantage of value chain analysis comes simply through systematizing the range of actors and effects that diseases can have on those actors and characterizing their interactions in a manner that is organized and efficient.

However, value chain analysis is operational has difficulty quantitatively measuring the full diversity of economic impacts. Value chain studies are typically intensive, requiring significant amounts of fieldwork to collect data, and such data is usually specific to a particular region or sub-chain within a region. Sample sizes are rarely representative statistically and, more often than not, the analysis is a hodgepodge of disparate data that are cobbled together from available sources. While these considerations should not discourage the use of value chain analyses to contextualize disease control policy for animal health systems, by themselves they are not sufficient to trace out the range of different impacts that might emerge from an animal disease. Nonetheless, value chain analyses add a piece to the puzzle that has been lacking in earlier studies.

A level up in aggregation from a standard value chain analysis, and much more widely available for analysis at level 4, are national (and sometimes regional) level databases known as Social Accounting Matrices, or SAMs (see Reinert and Roland-Holst, 1997). SAMs provide a snapshot across different sectors of an economy based on their input-output and other transaction relationships, linked with factors (land, labour, capital), household, and other institutional accounts. Figure 3 provides an illustration of a how a SAM is organized. SAMs are divided into different accounts that each represent a particular sector of the economy. These accounts can

Figure 3. Structure of a social accounting matrix

Receipts	Expenditures								
	1. Activities	**2. Commodities**	**3. Factors**	**4. Private Households**	**5. Enterprises**	**6. Recurrent State**	**7. Investment Savings**	**8. Rest of World**	**9. Total**
1. Activities		Marketed Production							Total Sales
2. Commodities	Intermediate Consumption			Private Consumption		State Consumption	Investment	Exports	Total Commodity Demand
3. Factors	Value Added								Value Added
4. Private Households			Wages, Salaries and Other Benefits		Distributed Profits and Social Security	Social Security and Other Current Transfers to Households		Net Foreign Transfers to Households	Private Household Income
5. Enterprises			Gross Profits					Net Foreign Transfers to Enterprises	Enterprise Income
6. Recurrent State	Indirect Taxes	Consumption Taxes plus Import Tariffs	Factor Taxes	Income Taxes	Enterprise Income Taxes			Net Foreign Transfers to State	State Revenue
7. Investmen Savings				Household Savings	Retained Earnings & Enterprise Savings	State Savings		Net Capital Inflows (=Foreign Savings)	Total Savings
8. Rest of World		Imports							Imports
9. Total	Total Payments	Total Commodity Supply	Total Factor Payments	Allocation of Private Household Income	Total Enterprise Expenditure	Allocation of State Revenue	Total Investment	Total Foreign Exchange	

Source: Reinert and Roland-Holst (1997).

be relatively aggregate (e.g., agriculture) or can disaggregate different sub-sectors (e.g., maize production, beef production, etc.). A SAM is principally an accounting framework that traces income and expenditure between all these entities, e.g. revenues earned by a sector by the sales of goods and services it provides, and the expenditures made in producing that good or service. By construction, the principle of double-entry bookkeeping makes each agent's total receipts (rows) equal to expenditures (columns).

Groups of accounts in the SAM are classified into different categories: activities, commodities, factors, institutions, capital, and rest-of-the-world. Activities accounts are the productive sectors of the economy that sells goods (commodities) to the domestic market and export internationally, while buying raw materials and factors to produce such goods. Commodities represent domestic product markets, buying the services of activities to make them and selling final products to households. A key distinction between activities and commodities is that activities are the actions that produce commodities, which are then sold to consumers. Factor markets include labour and capital markets that earn income from wages and rent, and pay salaries to households. Household accounts can be disaggregated by region and/or income level, thus providing insights on the links between the broader economy and households. Institutions include households and government. Households receive income from factor accounts, and pay taxes and for commodities purchased in the economy. Households may also pay/receive transfers to other households or the government. Government is a separate institution, receiving income from taxes and tariffs, and paying out subsidies (on activities) and provides transfers. The capital account represents savings and investment in the economy, with investment expenditures on commodities balanced by savings from households, firms, and government. Finally, the rest of the world (ROW) account denotes international transactions in the terms of exports and imports of goods, services, and remittances.

As will be illustrated in more detail in the next section, a useful aspect of SAMs is their ability to be operationalized in a variety of applications. At their most basic level, SAMs can be used to construct a matrix of multipliers that highlight the degree to which the economy and households react to changes in final demand stemming from government spending, investment, or exports. These multipliers can provide insights on which sectors respond more towards investment than others. As noted earlier, Roeder and Rich (2009) found that the livestock sectors of East Africa had relatively high activity multipliers (between 3-5, meaning that a US$1 increase in final demand would increase economywide output by US$3-5) compared to other sectors, suggesting that government spending in the sector (as in the case of investments in rinderpest campaigns) would be broadly beneficial. In animal health settings, Garner and Lack (1995), Ekboir (1999), and Mahul and Durand (2000) utilized SAMs in their analyses to measure the impacts of different interventions at a more macro level. SAMs can further be used as a database for more sophisticated computable general equilibrium (CGE) analyses that look more dynamically at the adjustment effects that could come from the shock of an animal disease (see Perry *et al.*, 2003 and Diao, 2010 for examples).

By themselves, SAMs do not capture dynamics or price changes associated with an economic shock. By assumption, SAMs multiplier frameworks are fixed price models that assume that changes in output result only from changes in final demand, while the technical input-output coefficients that govern production processes are assumed to be static (Reinert and Roland-Holst, 1997). However, dynamic adjustments will be a critical part of any analysis. These can be addressed in a SAM (see Miller and Blair, 1985 and the discussion in the next section), though not with the same level of sophistication as in other models. Partial equilibrium approaches (i.e., modelling supply and demand relationships at a sector level) allow the user to trace out the price and welfare impacts resulting from animal disease shocks (see Rich *et al.*, 2005), with methods established to compute dynamic welfare measures of producer and consumer surplus in a multimarket setting (see Bullock *et al.,* 1996 or Just *et al.,* 2004) and to examine impacts on different household groups (Minot and Goletti, 1998). Rich and Winter-Nelson (2007) utilized such a dynamic partial equilibrium approach in the analysis of FMD. Such techniques, however, are relatively data-intensive and, befitting a partial analysis, only capture a subset of the market and production effects associated with disease, while livelihood impacts are crudely modelled by income quartiles, for instance.

At a more macro-level than the SAM is a computable generally equilibrium model, or CGE. CGE models utilize SAMs as inputs, while defining a set of behavioral equations that capture the actions of agents within the economy (Sadoulet and de Janvry, 1995). Unlike SAMs, price effects are modeled, as are various types of sector and macroeconomic effects, including impacts on exchanges rates, government finances, and labor markets. CGE models have been used in animal health applications (see Rich, Winter-Nelson and Miller, 2005 for a review). While CGE approaches can capture more macro impacts, often lose sight of specific sectoral details depending on the level of disaggregation within the SAM. In addition, livelihood impacts from a CGE analysis are restricted to the household accounts provided in a given SAM as well.

Impacts at levels 5 and 6 are probably the most difficult to tease out. Value chain approaches are useful in revealing behavioural changes that could arise from animal disease control or eradication that might have local or global spillovers, while CGE analyses can point to global impacts that highlight impacts of trade bans and other inter-regional phenomena. A combination of "level 4" methods probably comes the closest to drawing out these influences, though an ideal analysis would employ non-market methods and organizational behavioral models to assess the costs of spillovers associated with rinderpest.

Ultimately, the analysis of any animal disease phenomenon will include tradeoffs between economic sophistication, institutional detail, and data availability. A particular need is to marry micro- and sector-level impacts with their broader effects on up and downstream markets within the value chain and with respect to other related and (seemingly) unrelated markets, and their resultant livelihood impacts. In the next section, we present a combination of sector-level, SAM, and CGE analyses to *ex-post* assessment of rinderpest control, providing details on the methodology and their application to the control and eradication of rinderpest in two case studies, Chad and India.

A new methodological framework for the *ex-post* assessment of rinderpest eradication: applications to Chad and India

The thrust for our method is to conduct a broader *ex-post* benefit-cost analysis of an animal health intervention at various levels of analysis. Our starting point is Golan *et al.* (2001) who adapted a SAM for the United States to examine the macroeconomic impacts of investments in food safety. In their analysis, the micro-level benefits of food safety control programmes and their costs to different segments of the economy were incorporated in a SAM multiplier analysis to gauge the totality of impacts within the economy. We take a similar tact, first weighing the benefits of control from the standpoint of livestock sector production with and without rinderpest control programmes against the additional cost of rinderpest control campaigns. We further extend the analysis of Golan *et al.* (2001) by looking at these net benefits dynamically, tracing out the alternative growth path that could exist in the absence of rinderpest control campaigns and comparing those impacts with the actual growth that occurred in the economy at large. This necessitates the use of both SAM and CGE analyses to obtain a fuller picture of the benefits from rinderpest eradication.

In line with the levels of analysis provided in the previous section, the methodology that we utilize adopts a sequential strategy in which the level of aggregation of associated net benefits from rinderpest eradication is gradually increased, with each step based on outputs from the subsequent one. In particular, we do the following:

- First, define a counterfactual scenario in terms of the biological impacts of rinderpest (with and without eradication campaigns) and their cost implications;
- Calculate and compare sector-level benefits in the livestock sector with and without rinderpest control, based on available price and production data, and simulation analysis of cattle production trends, thus trying to tease out an approximation of behavioral impacts resulting from rinderpest control (levels -3);
- Compute the additional costs associated with rinderpest control campaign, based on available data, comparing these costs to benefits and calculating a sector-level benefit-cost ratio;
- Compute multipliers from available SAMs to examine the growth linkages from rinderpest control, including a decomposition of multipliers to highlight paths of influence from economic shocks and their livelihood effects; and apply these to the sector-level BCR (level 4);
- Project long-run dynamic impacts from rinderpest control based on a CGE analysis, using the SAM in question and calibrated based on growth patterns and the counterfactual scenario (levels 4 and 6).

As an example of applying this methodology, we consider the case of rinderpest in Chad and India. Brief profiles of these two cases are provided below.

Chad

Oussiguere (2010) notes that rinderpest was first officially detected in Chad in 1913. A major epidemic in 1913-1914 killed nearly 70 percent of cattle stocks, or about 1 million cattle. Rinderpest control did not begin in Chad until 1933 with the establishment of vaccine centers in the country, and vaccination provided progressively improved control during the 1950s. However, as noted by Oussiguere (2010), better control through vaccination also coincided with lessened vigilance against the disease, leading to a rise in outbreaks in the late 1950s.

Internationally coordinated control efforts in Chad commenced with JP15 that began in September 1962. Between 1962 and 1970, outbreaks of rinderpest steadily fell (Table 2). Vaccination coverage peaked in the first year of JP15, with over 83 percent of cattle vaccinated in 1962, and fell erratically from 1963-1970 (Table 2). Vaccination coverage post-JP15 ranged between 29 percent and 44 percent during 1971 to 1977, then ceased during 1978-1982. A major outbreak in 1983, linked to movement of infected cattle, reportedly killed up to 337 500 head of cattle, after which vaccination coverage increased markedly in 1983 and 1984, before falling to a range of 43 percent to 54 percent between 1985 and 1988 (Oussiguere, 2010). The PARC programme, starting in Chad in 1989, ramped up vaccination coverage to over 76 percent by 1992, which was gradually reduced during the remainder of the decade as sero-surveillance programmes were established to verify the absence of infection.

For Chad, our counterfactual scenario assumes that in the absence of rinderpest control campaigns, the disease is primarily controlled via movement controls and targeted interventions upon the discovery of disease. This counterfactual largely characterizes control efforts pre-JP15 during the 1950s. Thus, this implies that the added costs from rinderpest campaigns can be assumed to be those spent by donors and national governments alike, over and beyond other ancillary disease control programmes.

Next, from the benefits side, our primary metrics at the sector-level include valuing major outputs from the livestock sector: live animals, meat, and milk. These necessitate time-series data on production and prices, some of which is available on data sources in public domain such as FAOSTAT. To facilitate the comparison

Table 2. Rinderpest outbreaks during JP15 in Chad, 1963-1970

Years	Number of outbreaks	Number of infected cattle	Number of cattle deaths	Cattle deaths per outbreak	Vaccination coverage rate (%)
1963	33	980	716	22	83
1964	9	1,892	1,802	200	69
1965	7	658	257	37	40
1966	46	2,152	756	16	79
1967	39	967	660	17	41
1968	25	446	267	11	34
1969	26	927	516	20	32
1970	19	408	228	12	29
Average	26	1,054	650	42	

Source: Oussiguere (2010)

of actual events with rinderpest control with the counterfactual scenario, in which rinderpest control campaigns were assumed not to have occurred, we utilize the DynMod simulation software (Lesnoff *et al.*, 2007; 2008). DynMod projects the dynamic population behavior of cattle herds based on assumptions and observed data on herd demographics, offtake rates, death rates, and reproduction rates. Based on parameter assumptions provided in Lesnoff *et al.* (2008) and observations with FAOSTAT data on periods of production shocks (e.g., from droughts), we calibrate DynMod to roughly reproduce the baseline production data reported from FAOSTAT. The counterfactual is constructed by adding the additional mortality engendered by rinderpest as observed from data pre-JP15, which provides an alternative production projection. In the absence of information on price elasticities and because the magnitude of production differences are generally small, we assume that prices in both the "with" and "without" scenarios are the same.

We also considered the impact of morbidity as well in our calculations. From our data, we have information on both affected and dead animals, which allows us to construct a net morbidity percentage of surviving, affected animals. This percentage is used to adjust the volume of milk available from sick animals, as animals affected by rinderpest will have lower milk yields than healthy ones. We assumed that milk production is reduced by 15 percent in affected but surviving animals. This figure is relatively small, but important in contexts where milk production is important (e.g., India).

Table 2 and Table 3 illustrate the computation of mortality rates attributed to the "without" case in Chad. Between 1963-1970, an average of 42 cattle were reported to die per observed outbreak. Using this figure and applying it to the observed number of outbreaks before JP15 (1958-1961) gives us an approximate number of animals that died because of rinderpest. Extrapolating population numbers back to

Table 3. Rinderpest outbreaks pre-JP15 in Chad, 1958-1961

Year	Number of outbreaks	Number of deaths, based on 1963-1970 average	Animal population*	% mortality from rinderpest
1958	351	14,677	3,955,432	0.37 %
1959	367	15,346	4,012,786	0.38 %
1960	235	9,826	4,070,971	0.24 %
1961	324	13,548	4,130,000	0.33 %
Average		13,349		0.33 %
Additional outbreaks relative to 1963-1970 average	294	12,699		0.32%
Additional outbreaks relative to highest mortality rate during 1963-1970				0.08%
Additional outbreaks relative to lowest mortality rate during 1963-1970				1.54%

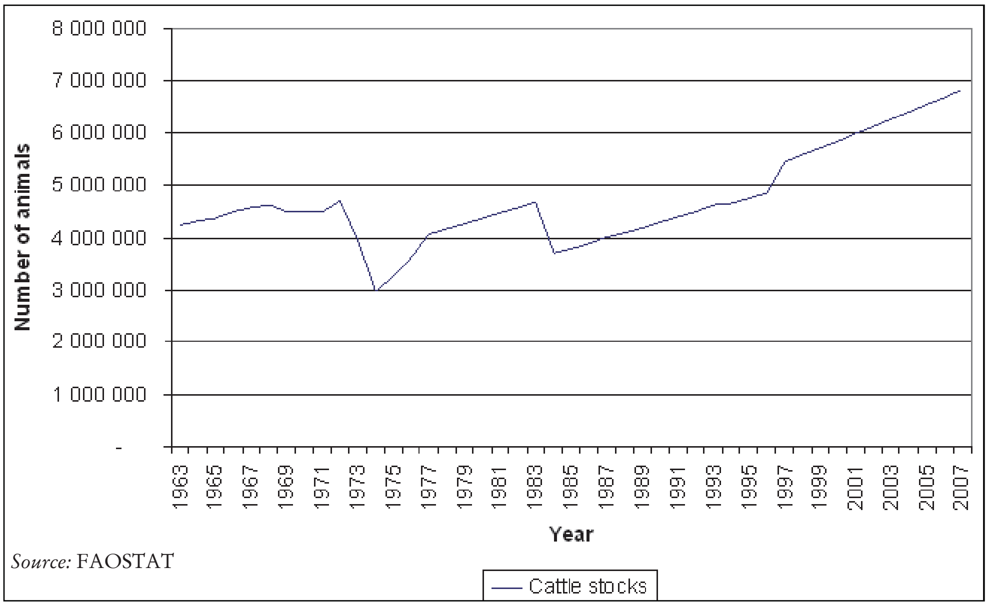
Source: Oussiguere (2010).

* Populations for 1958-1960 extrapolated from 1.45% growth rate observed in the 1960s.

the late 1950s using 1960s population growth trends provides us with total animal stocks that are used in Table 3 to calculate mortality rates associated with rinderpest. This additional mortality is added to standard mortality rates in DynMod to provide an alternative population projection in the absence of rinderpest control. As a means of conducting some sensitivity analysis, we also calculated representative "high" and "low" additional mortality in which the highest number of deaths per outbreak during 1963-1970 (200) and lowest number of deaths per outbreak (11) were used instead of the average and then applied to the 1950s data. This gives us a high additional mortality rate due to rinderpest of 1.54 percent and a low additional mortality rate of 0.08 percent. Additional sensitivity analysis whereby the mortality rate was incrementally increased by 0.05 was also conducted to determine the break-even BCR.

One of the challenges in calibrating the production data is accounting for various exogenous shocks to cattle populations, particularly those attributable to droughts. In Chad, major production shocks occurred in 1969, 1973-1974, and 1984 (Figure 4). The latter shock included a combination of drought with a major rinderpest outbreak that Oussiguere (2010) reported killing 337 500 cattle. To account for these shocks, we adjusted the standard mortality rates in DynMod to roughly approximate the observed trend. In a normal year, we assume that 11.2 percent of female calves (less than 1 year old) and 10.2 percent male calves die in a given year, while older animals die at a 5.8 percent rate for females and 5.2 percent for males. In 1969, we assumed that mortality rates increased by 50 percent. In 1973, mortality rates for males and females were assumed to be 35 percent for young stock and 15 percent for older stock; these were doubled in the major drought year of 1974. In 1984, we decomposed mortality (assumed at the same rates as 1974) into a drought shock and a rinderpest shock. The rinderpest shock accounted for about 35 percent of deaths in 1984. We assume that in the counterfactual case, these additional rinderpest deaths would not occur, as without control campaigns, there

Figure 4. Cattle population trends in Chad, 1963-2007



Source: FAOSTAT

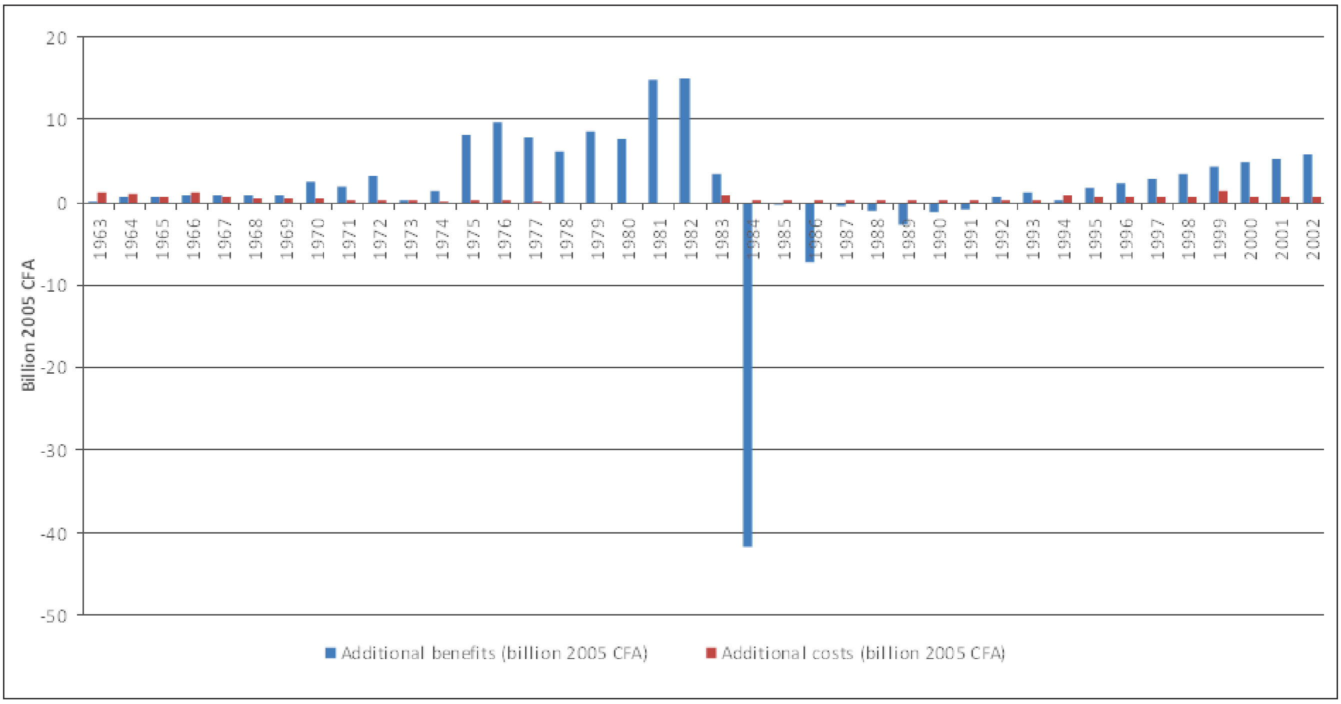
would be low-level endemicity of disease that could preclude larger pandemics.

Figure 5 illustrates the projected population trends with and without rinderpest control as computed from DynMod, comparing the average, high, and low counterfactual cases. Interestingly, populations in the counterfactual are actually higher post-1984 for several years, though populations under the control case eventually recover. This has implications in the valuation of benefits, as the benefits with control would be *lower* in such years, highlighting the need for a much longer time horizon to fully assess the benefits of rinderpest eradication. The "high rinderpest mortality" case is particularly noteworthy in that cattle populations remain at depressed levels (2007 populations are slightly less than those in the early 1960s), whereas under "low rinderpest mortality," populations are higher than under rinderpest eradication.

Based on these projections, conversion rates for meat and milk, and offtake rates for domestic and export sales, we next compute values for the production of animal, meat, and milk. Price data is not available for Chad, so we proxy price data in Chad using figures for Niger. Price data for Niger is available from FAOSTAT for 1991-2007. Data on cattle prices from 1968-1988 comes from the dataset used in Fafchamps and Gavian (1995), with conversion rates to meat and milk from live animal prices based on the methodology used in FAOSTAT. For 1963-1967, prices were estimated by deflating nominal 1968 prices by the Niger CPI. All values were then converted to real values in CFA based on the GDP deflator provided in the World Bank's World Development Indicators.

The costs of rinderpest control in Chad were primarily extracted from the data reported in Lepissier (1971) and Oussiguere (2010). Oussiguere (2010) cites the number of vaccinations administered during JP15 and post-JP15 until 1988, but

Figure 5. Additional benefits and costs associated with rinderpest control in Chad: baseline case.



does not give a cost estimate. Lepissier (1971) estimates that the unit costs of vaccine administration in Chad based on aggregate JP15 expenditures were 59.8 CFA, of which 30.1 CFA are attributed to international donor funds and 28.9 CFA are based on national level contributions. Between 1963-1970, we apply this figure (in constant real 2 000 CFA) to the number of vaccinations applied based on Oussiguere (2010). Between 1971-1988, we assume that the real unit cost of vaccination is the national cost component provided in Lepissier (1971) of 28.9 CFA. For the costs of the PARC and PACE programmes, Oussiguere (2010) reports aggregate costs associated with both programmes. As an approximation, we assumed that these funds were divided evenly in each year of the respective programme. All costs were converted to 2 000 constant CFA using the GDP deflator for Chad computed by the World Bank.

Table 4 summarizes the net benefits and additional costs associated with rinderpest control during the period 1963-2002 where data on benefits and costs were available, looking at three scenarios (baseline, high mortality, and low mortality), with assumptions on additional mortality due to rinderpest found in Table 3. Figure 5 illustrates the additional benefits and costs associated with the baseline case. Note that net benefits to rinderpest control in the baseline from 1984-1994 were negative based on our assumption that rinderpest pandemics would be lessened in the presence of constant endemicity, thus providing a very conservative estimate of the impacts of rinderpest control.

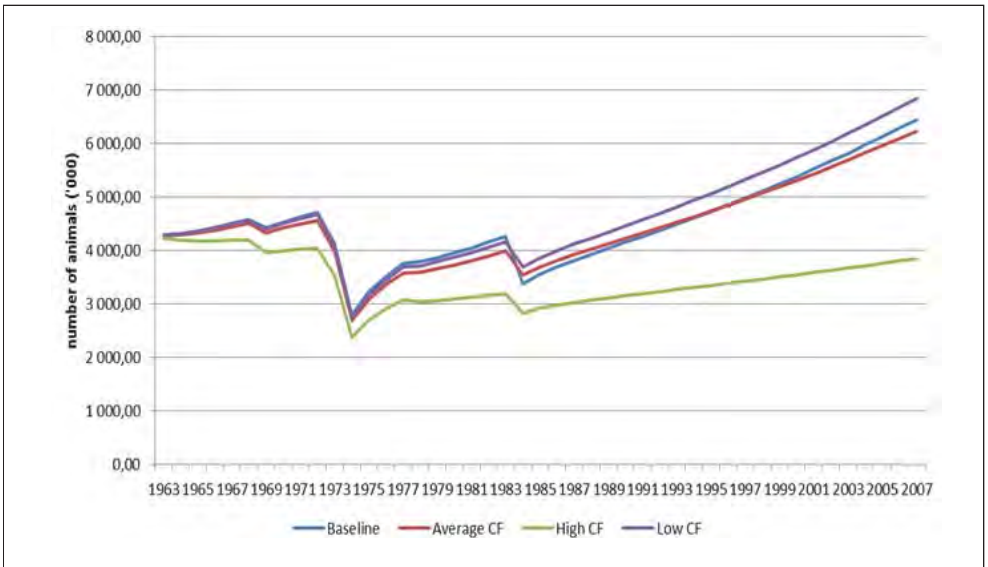
Using a 5 percent discount rate to both the stream of benefits and costs yields a baseline scenario benefit-cost ratio at a sector level of just over four. This is slightly above the BCRs of 1.06-3.84 reported in Tambi *et al.* (1999) that evaluated the PARC programme alone. This first-round analysis likely underestimates both benefits and costs, particularly the latter which were not readily available other than the figures given in Oussiguere (2010). Note that these average results are extremely sensitive to the choice of scenario considered and in particular the mortality rate. Under the high mortality case, the benefits to rinderpest eradication relative to their costs are extremely high, with a benefit-cost ratio of over 47 over the 40-year period. This is due entirely to the marked variation in population levels, which under higher levels of rinderpest mortality are much lower than under eradication (see Figure 6). By contrast, under a situation of low rinderpest mortality, the benefit-cost ratio is actually negative by virtue of impact of the 1983-84 drought. In the low rinderpest mortality case, mortality during the drought is lower than eradication, and population growth rates under eradication and this scenario are nearly the same. This implies that populations post-drought in the low mortality scenario are actually *higher*. However, if we look at BCRs pre-drought (1963-1983) in this low mortality scenario, we find these are positive (2.71), suggesting a need to better understand the differential impacts of mortality stemming for drought and rinderpest both.

In Figure 7, we conducted a sensitivity analysis to map the relationship between the benefit-cost ratio and the mortality rate associated with rinderpest. In the analysis, we also considered the sensitivity of the BCR to the percentage of deaths associated with rinderpest during the 1984 drought. In the baseline, as mentioned above, we assumed that 35 percent of deaths were due to rinderpest in the 1984 drought. In the sensitivity analysis, we consider the impacts on the BCR if that percentage

Table 4. Assessment of benefits and costs of rinderpest eradication, 1963-2002 (billion CFA, 2000 prices)

Year	Benefits			Costs
	Baseline	High mortality	Low mortality	
1963	0.072	0.35	0.018	1.149
1964	0.601	2.89	0.150	0.953
1965	0.712	3.39	0.178	0.566
1966	0.865	4.10	0.217	1.132
1967	0.826	3.88	0.207	0.587
1968	0.831	3.87	0.209	0.500
1969	0.923	4.23	0.233	0.451
1970	2.431	11.27	0.612	0.416
1971	2.025	9.29	0.511	0.312
1972	3.326	15.23	0.840	0.258
1973	0.267	-1.91	0.721	0.286
1974	1.414	2.59	1.173	0.160
1975	8.147	31.29	3.314	0.205
1976	9.717	37.72	3.811	0.231
1977	7.779	30.52	2.919	0.170
1978	6.140	24.23	2.222	0.000
1979	8.536	33.57	3.106	0.000
1980	7.686	30.27	2.737	0.000
1981	14.753	57.93	5.312	0.000
1982	15.008	58.94	5.316	0.000
1983	3.384	13.31	1.051	0.884
1984	-41.624	-54.20	-38.862	0.350
1985	-0.264	17.17	-4.184	0.241
1986	-7.304	59.13	-22.146	0.246
1987	-0.516	28.83	-7.231	0.323
1988	-1.068	33.01	-8.883	0.305
1989	-2.670	57.64	-16.489	0.324
1990	-1.223	51.33	-13.389	0.297
1991	-0.747	56.91	-14.185	0.287
1992	0.746	48.43	-10.546	0.326
1993	1.216	48.71	-10.115	0.320
1994	0.335	100.56	-23.316	0.793
1995	1.781	74.13	-15.526	0.721
1996	2.326	56.93	-10.905	0.640
1997	2.949	66.24	-12.446	0.630
1998	3.346	61.53	-10.933	0.589
1999	4.283	68.81	-11.676	1.425
2000	4.943	74.07	-12.241	0.750
2001	5.178	71.90	-11.507	0.657
2002	5.757	72.77	-11.136	0.647
NPV@5%	**32.46**	**380.89**	**-47.06**	**8.08**
BCR	**4.02**	**47.15**	**-5.83**	

Figure 6. Comparison of cattle population projections with and without rinderpest control under different scenarios, 1963-2



Source: Model simulations with DynMod

was reduced (ranging from 5 percent to 25 percent). As noted in the figure, positive benefits to rinderpest control at a sector-level are highly sensitive both to assumptions on the additional mortality associated with rinderpest as well as the drought impact, suggesting the need for careful research on these mortality-related effects.

The next step in the analysis is to examine the economywide impacts of rinderpest control. This necessitates analysis with a social accounting matrix that was developed for Chad (Garber, 2009). The structure of accounts in the Chad SAM is given in Table 5. We start by conducting a standard multiplier analysis by generating a multiplier matrix and then applying this to a hypothetical vector of exogenous shocks based on our "with" and "without" scenarios. It is instructive to review how this is accomplished in a SAM. Let A be an *n X n* matrix of technical coefficients of productive, endogenous sectors in the SAM, where the entry a_{ij} is the amount of sector *i* used in the production of sector *j's* output, X_{ij} (Sadoulet and de Janvry, 1995). Let X be an *n X 1* vector of outputs of endogenous sectors, and let F be an *n X 1* vector of final demand of exogenous sectors, representing the horizontal sum of outputs from government accounts, capital accounts, and rest-of-the-world accounts. Then, in matrix form, the relationships in our SAM can be written as:

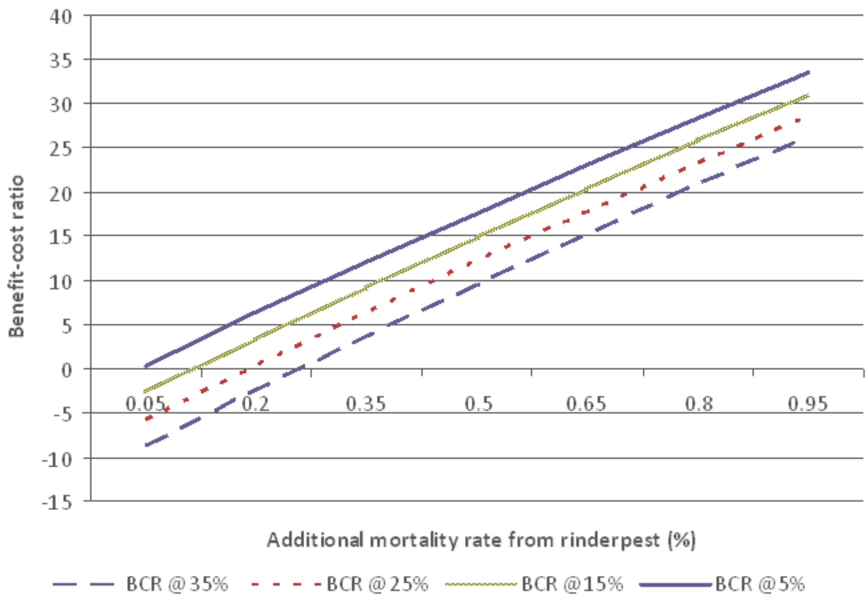
$$AX + F = X$$

If we rearrange terms and isolate output as a function of final demand, we obtain the following equation, with the inverse of the expression (I-A) is what is known as the multiplier matrix:

$$(I - A)^{-1} F = X$$

The multiplier matrix, as noted earlier, tells us how much output is generated from a one-unit shock in final demand, such as government spending, investment, or exports. When the multiplier matrix is multiplied by specific sector-by-sector

Figure 7. Sensitivity analysis of benefit-cost ratio eradication in Chad, based on different mortality rates and percentage of rinderpest deaths associated with drought.



Source: Model simulations with DynMod. Note: the "BCR @" labels refer to the percentage of 1984 drought deaths associated with rinderpest. The baseline assumes 35 percent of deaths in 1984 were rinderpest-related, which is relaxed in the sensitivity analysis illustrated above.

changes in final demand, we can trace the change in output, sector-by-sector, engendered by this:

$$(I - A)^{-1}\Delta F = \Delta X \qquad (3)$$

Table 6 and Table 7 provide multipliers associated with a number of agricultural sectors in Chad. Both activity multipliers (reflecting shocks to productive output) (Table 6) and commodity multipliers (reflecting shocks to supply) (Table 7) are provided. We read the multipliers down each column as follows, taking the livestock activity column as an example. In this case, a one-unit increase in government spending on livestock production activities would lead to an increase in total productive output of 3.49 units, domestic supply of 3.73 units, factors of production of 2.48 units, and household income of 2.62 units (Table 6). Commodity multipliers for livestock are similar in magnitude, though domestic supply increases more (4.63) relative to a one-unit shock to livestock production (Table 7). Agricultural activity and commodity multipliers tend to be higher than industrial ones (with the exception of cotton milling), while household multipliers are much higher for injections into agriculture than industry, suggesting greater income generation potential from agriculture. Household multipliers for livestock are on par with crop production, cotton, and fisheries, and provide more income for enterprises than other agriculture activities. These multipliers suggest that the net benefits from rinderpest eradication will be a significant order of magnitude higher than those reported at the sector level and suggest the benefit-cost ratio associated with rinderpest control is much higher. As a very crude approximation, applying

Table 5. Accounts in the Chad social accounting matrix (2000)

Account name	Description (type of account)
Aag	Agriculture (activities)
Aagcot	Cotton crops (activities)
Alive	Livestock (activities)
Afish	Fisheries (activities)
Aman	Manufacturing (activities)
Acot	Cotton fiber manufacturing (activities)
Adev	Oil development (activities)
Acon	Construction (activities)
Ainf	Informal manufacturing (activities)
Aserv	Services (activities)
Agov	Government (activities)
Cag	Agriculture (commodities)
Cagcot	Cotton crops (commodities)
Clive	Livestock (commodities)
Cfish	Fisheries (commodities)
Cman	Manufacturing (commodities)
Ccot	Cotton fiber manufacturing (commodities)
Cdev	Oil development (commodities)
Ccon	Construction (commodities)
Cinf	Informal manufacturing (commodities)
Cserv	Services (commodities)
Cgov	Government (commodities)
Fland	Land (factor accounts)
Fcapf	Capital, formal sector (factor accounts)
Fcapl	Capital, informal sector (factor accounts)
Flabp	Labour, privileged sector (factor accounts)
Flabn	Labour, non-privileged sector (factor accounts)
Hrurag	Rural agricultural households (households)
Hrurpub	Rural public sector (households)
Hurbinf	Urban informal sector (households)
Hurbcr	Urban capitalist-rentier (households)
Hurbpub	Urban public sector (households)
Hurbw	Urban wage workers (households)
Hent	Enterprises (households)

Source: Garber (2009)

the commodity multiplier of 4.63 to the BCR at a sector-level gives an aggregate BCR of well over 18.

Multipliers can be further decomposed to determine the paths of transmission of economy activity to assess who gains (and how) from the added-value generated in the economy. Following techniques developed in Defourny and Thorbecke (1984) and applied by Roland-Holst and Otte (2007) in the context of livestock and livelihood

Table 6. Activity multipliers for Chad

		Agriculture	Cotton	Livestock	Fisheries	Manufacturing	Cotton milling	Oil development	Construction	Informal activities	Services	Government
Activities	Agriculture	1.60	0.59	0.53	0.55	0.39	0.49	0.27	0.32	0.38	0.38	0.35
	Cotton	0.00	1.00	0.00	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.00
	Livestock	0.25	0.25	1.22	0.23	0.63	0.21	0.17	0.19	0.22	0.18	0.19
	Fisheries	0.06	0.06	0.06	1.10	0.04	0.05	0.07	0.20	0.06	0.05	0.05
	Manufacturing	0.35	0.35	0.33	0.35	1.37	0.30	0.31	0.35	0.37	0.31	0.33
	Cotton milling	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
	Oil development	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
	Construction	0.01	0.01	0.01	0.01	0.01	0.01	0.23	1.02	0.01	0.01	0.02
	Informal activities	0.31	0.31	0.30	0.31	0.20	0.26	0.14	0.18	1.32	0.19	0.20
	Services	0.99	0.99	1.03	0.99	0.91	1.04	1.16	1.01	0.93	2.05	0.98
	Government	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	1.01
TOTAL ACTIVITY		3.58	3.57	3.49	3.55	3.57	4.09	3.35	3.28	3.29	3.18	3.13
Commodities	Agriculture	0.80	0.79	0.71	0.74	0.52	0.66	0.36	0.43	0.51	0.51	0.46
	Cotton	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00
	Livestock	0.27	0.27	0.23	0.24	0.68	0.23	0.18	0.21	0.23	0.19	0.21
	Fisheries	0.08	0.08	0.08	0.13	0.06	0.07	0.09	0.27	0.07	0.06	0.06
	Manufacturing	1.04	1.04	1.00	1.05	1.10	0.91	0.93	1.05	1.12	0.94	0.99
	Cotton milling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Oil development	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Construction	0.01	0.01	0.01	0.01	0.01	0.01	0.23	0.02	0.01	0.01	0.02
	Informal activities	0.32	0.32	0.30	0.32	0.20	0.26	0.14	0.18	0.33	0.20	0.21
	Services	1.32	1.32	1.37	1.31	1.22	1.39	1.55	1.34	1.23	1.40	1.31
	Government	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01
TOTAL COMMODITY		3.85	3.84	3.73	3.82	3.79	4.27	3.49	3.50	3.51	3.31	3.26

cont.

Table 6. *Cont.d*

		Agriculture	Cotton	Livestock	Fisheries	Manufacturing	Cotton milling	Oil development	Construction	Informal activities	Services	Government
Factors	Land	0.24	0.24	0.40	0.22	0.22	0.19	0.08	0.10	0.10	0.09	0.09
	Capital, formal sector	0.10	0.10	0.10	0.10	0.17	0.20	0.21	0.19	0.09	0.16	0.29
	Capital, informal sector	0.38	0.38	0.39	0.38	0.38	0.39	0.41	0.41	0.57	0.68	0.36
	Labor, privileged sector	0.05	0.05	0.06	0.05	0.08	0.08	0.09	0.13	0.05	0.10	0.30
	Labor, non-prvi-leged sector	1.70	1.71	1.54	1.75	0.99	1.38	0.66	0.83	1.08	0.89	0.83
TOTAL FACTOR		2.46	2.48	2.48	2.50	1.84	2.23	1.45	1.66	1.90	1.93	1.87
Households	Rural agricultural	1.11	1.12	1.10	1.13	0.71	0.91	0.47	0.58	0.73	0.64	0.57
	Rural public sector	0.17	0.17	0.18	0.17	0.12	0.15	0.08	0.11	0.11	0.10	0.16
	Urban informal sector	0.28	0.29	0.26	0.29	0.18	0.24	0.13	0.16	0.21	0.19	0.15
	Urban capitalist-rentier	0.18	0.18	0.17	0.19	0.11	0.15	0.08	0.10	0.13	0.12	0.10
	Urban public sec-tor	0.28	0.29	0.26	0.29	0.19	0.25	0.14	0.18	0.19	0.18	0.26
	Urban wage work-ers	0.15	0.15	0.14	0.15	0.10	0.13	0.08	0.11	0.10	0.10	0.16
	Enterprises	0.43	0.44	0.52	0.43	0.48	0.50	0.47	0.46	0.50	0.62	0.50
TOTAL HOUSEHOLD		2.61	2.62	2.62	2.64	1.90	2.32	1.46	1.70	1.97	1.96	1.90

Source: Computed from 2000 Chad SAM of Garber (2009)

Table 7. Commodity multipliers for Chad

		Agriculture	Cotton	Livestock	Fisheries	Manufacturing	Cotton milling	Oil development	Construction	Informal activities	Services	Government
Activities	Agriculture	1.24	0.58	0.51	0.48	0.20	0.48	0.26	0.31	0.37	0.29	0.34
	Cotton	0.00	0.98	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00
	Livestock	0.22	0.24	1.15	0.20	0.24	0.21	0.16	0.19	0.21	0.14	0.19
	Fisheries	0.05	0.06	0.06	0.85	0.02	0.05	0.07	0.20	0.05	0.03	0.05
	Manufacturing	0.31	0.34	0.32	0.32	0.51	0.30	0.30	0.34	0.36	0.23	0.32
	Cotton milling	0.00	0.00	0.00	0.00	0.00	0.98	0.00	0.00	0.00	0.00	0.00
	Oil development	0.00	0.00	0.00	0.00	0.00	0.00	0.98	0.00	0.00	0.00	0.00
	Construction	0.01	0.01	0.01	0.01	0.01	0.01	0.22	0.99	0.01	0.01	0.02
	Informal activities	0.26	0.30	0.28	0.27	0.10	0.25	0.14	0.17	1.29	0.14	0.20
	Services	1.04	0.97	1.03	1.09	0.66	1.02	1.14	0.98	0.91	1.54	0.96
	Government	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.98
TOTAL ACTIVITY		3.13	3.49	3.37	3.23	1.74	4.00	3.28	3.20	3.21	2.39	3.06
Commodities	Agriculture	1.67	0.77	0.68	0.65	0.26	0.65	0.35	0.42	0.50	0.38	0.45
	Cotton	0.00	1.00	0.00	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.00
	Livestock	0.23	0.26	1.22	0.21	0.26	0.22	0.17	0.20	0.23	0.14	0.20
	Fisheries	0.07	0.08	0.08	1.11	0.03	0.07	0.09	0.26	0.07	0.05	0.06
	Manufacturing	0.92	1.02	0.97	0.96	1.53	0.89	0.91	1.02	1.09	0.70	0.96
	Cotton milling	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
	Oil development	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
	Construction	0.01	0.01	0.01	0.01	0.01	0.01	0.23	1.02	0.01	0.01	0.02
	Informal activities	0.26	0.31	0.29	0.28	0.10	0.26	0.14	0.18	1.32	0.15	0.20
	Services	1.38	1.29	1.37	1.45	0.88	1.36	1.51	1.31	1.21	2.05	1.28
	Government	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.00	1.01
TOTAL COMMODITY		4.55	4.75	4.63	4.67	3.07	5.17	4.41	4.42	4.43	3.49	4.19

cont.

Table 7. *cont.d*

		Agriculture	Cotton	Livestock	Fisheries	Manufacturing	Cotton milling	Oil development	Construction	Informal activities	Services	Government
Factors	Land	0.19	0.23	0.38	0.18	0.09	0.18	0.08	0.10	0.10	0.07	0.09
	Capital, formal sector	0.10	0.09	0.10	0.10	0.09	0.20	0.21	0.19	0.09	0.12	0.28
	Capital, informal sector	0.38	0.37	0.39	0.40	0.24	0.38	0.40	0.40	0.56	0.51	0.35
	Labor, privileged sector	0.05	0.05	0.05	0.06	0.04	0.08	0.09	0.13	0.05	0.07	0.30
	Labor, non-privileged sector	1.39	1.67	1.47	1.48	0.49	1.35	0.65	0.81	1.06	0.67	0.81
TOTAL FACTOR		2.12	2.42	2.39	2.22	0.95	2.18	1.42	1.62	1.86	1.45	1.83
Households	Rural agricultural	0.92	1.09	1.06	0.96	0.35	0.89	0.46	0.56	0.72	0.48	0.56
	Rural public sector	0.14	0.17	0.17	0.15	0.06	0.14	0.08	0.11	0.10	0.08	0.15
	Urban informal sector	0.24	0.28	0.25	0.25	0.09	0.23	0.13	0.15	0.20	0.14	0.15
	Urban capitalist-rentier	0.15	0.18	0.16	0.16	0.06	0.15	0.08	0.10	0.13	0.09	0.10
	Urban public sector	0.24	0.28	0.25	0.25	0.09	0.24	0.14	0.18	0.18	0.14	0.25
	Urban wage workers	0.12	0.14	0.13	0.13	0.05	0.13	0.08	0.10	0.10	0.08	0.16
	Enterprises	0.42	0.43	0.50	0.43	0.27	0.48	0.46	0.45	0.49	0.47	0.49
TOTAL HOUSEHOLD		2.23	2.56	2.52	2.34	0.97	2.27	1.43	1.66	1.92	1.47	1.85

Source: Computed from 2000 Chad SAM of Garber (2009) benefits, we provide estimates of these linkages for the six different household groups found in the SAM (Table 8). The data indicates that, with the exception of rural public sector groups, shocks to livestock supply are modulated through manufacturing activities, suggesting more complex interactions within the value chain that one might first conceive. While not surprising for urban households, it highlights the diversification of rural households into a variety of activities and that the benefits of rinderpest eradication will have a variety of non-livestock related benefits as well.

We can further use our SAM using the methodology employed by Thorbecke (1992), who conducted a number of experiments in which alternative final demand vectors were generated and multiplied by the multiplier matrix to examine the impacts of alternative structural adjustment policies in Indonesia. This type of analysis can provide a representative indication of the benefits of rinderpest eradication in a particular, discrete time period, though is less suitable for a longer-run analysis given issues concerning the stability of multiplier matrix and potential price adjustments, not to mention the difficulties inherent in dynamic analysis with a SAM (Miller and Blair, 1985).[2]

In our experiment, we first assume that the 2000 SAM reflects the scenario in which rinderpest control has occurred, so any shock to the economy would reflect the situation without rinderpest control. To simulate this for the year 2000, we assume that there would be a loss in the economy in the amount of the net benefits attributed to rinderpest control. As reported in Table 4, the net benefits to rinderpest control in 2000 were calculated at 4.94 billion CFA. We can think of this shock as a loss in private investment in the economy suffered by those in the livestock value chain. In the Chad SAM, we simulate this by reducing investment by rural agricultural households by 4.94 billion CFA (i.e., the intersection in the "Caphetot" account column and "Hrurag" account row). For costs associated with this policy, we assume that there is a reduction in government spending on the livestock sector (production activity) in the amount of the control programmes in that year (750 million CFA). However, as government spending is fungible, we assume that the 750 million CFA that is not spent on livestock is reallocated in proportion to the structure of government spending given in the Chad SAM.

Table 9 provides an estimate of the sector-by-sector changes in output associated with the counterfactual scenario in 2000, the base year of the SAM. The results show lower levels of production and income associated with the absence of rinderpest control. Rural incomes in 2000 are 2.6 percent lower relative to the baseline cost in which rinderpest control takes place, while other household groups have incomes that are over 1 percent lower without rinderpest control. Significant losses on a production basis occur in the agricultural sector (-1.7 percent), manufacturing (-1 percent), and the informal sector (-1.5 percent), all of which suggest that rinderpest control has strong poverty reduction impacts in these sectors where broader-based employment opportunities exist. Measuring GDP at factor cost reveals that in the absence of rinderpest control, GDP would be 1 percent lower compared to the case with rinderpest control.

[2] Golan *et al.* (2001) adopt this approach in the context of HAACP control in which they use the SAM to simulate economy-wide effects based on a 20-year stream of discounted costs and benefits. However, in that case, the shocks conceived relative to their SAM accounts are small whereas adopting a similar approach using the Chad SAM would present theoretical problems that would be difficult to justify, as the shocks here would be quite large. This further suggests the utilization of CGE methods to project out the benefits dynamically.

Table 8. Path decomposition for household groups in Chad

Path Target	<-Sect1	<-Sect2	<-Sect3	<-Sect4	<-Sect5	Global Effect	Direct Effect	Path Multiplier	Total Effect	Percent of Total	Total Percent
Hrurag	Clive					0.241	0.024	1.959	0.047	19.3	19.3
Hrurag	Cag	Aag	Clive				0.009	2.316	0.021	8.5	27.9
Hrurag	Cman	Aman	Clive				0.025	2.467	0.06	25.1	52.9
Hrurag	Cinf	Ainf	Clive				0.001	2.299	0.003	1.1	54
Hrurag	Cag	Aag	Cman	Aman	Clive		0.002	2.875	0.007	2.8	56.8
Hrurag	Cag	Aag	Fland	Hrurpub	Clive		0.001	2.352	0.002	0.6	57.5
Hrurag	Cag	Aag	Flabn	Hrurpub	Clive		0.003	2.538	0.008	3.2	60.7
Hrurag	Cinf	Ainf	Cman	Aman	Clive		0.005	2.871	0.015	6.1	66.8
Hrurag	Cinf	Ainf	Flabn	Hrurpub	Clive		0.001	2.647	0.001	0.6	67.3
Hrurag	Cserv	Aserv	Cman	Aman	Clive		0.004	3.63	0.016	6.6	73.9
Hrurpub	Clive					0.405	0.195	1.292	0.252	62.2	62.2
Hrurpub	Hrurag	Clive					0.001	2.032	0.001	0.3	62.5
Hrurpub	Cag	Aag	Clive				0.006	1.919	0.011	2.7	65.2
Hrurpub	Cman	Aman	Clive				0.025	1.69	0.042	10.4	75.6
Hrurpub	Cinf	Ainf	Clive				0.001	1.614	0.002	0.4	76
Hrurpub	Hrurag	Cman	Aman	Clive			0.001	2.543	0.001	0.4	76.3
Hrurpub	Hurbw	Cman	Aman	Clive			0.001	1.822	0.002	0.5	76.8
Hrurpub	Cag	Aag	Cman	Aman	Clive		0.002	2.42	0.004	0.9	77.7
Hrurpub	Cag	Aag	Flabn	Hrurag	Clive		0.002	2.538	0.004	0.9	78.7
Hrurpub	Cinf	Ainf	Cman	Aman	Clive		0.005	2.072	0.01	2.5	81.2
Hrurpub	Cserv	Aserv	Cman	Aman	Clive		0.004	2.701	0.012	2.9	84.1

cont.

Table 8. *Cont.d*

Path Target	<-Sect1	<-Sect2	<-Sect3	<-Sect4	<-Sect5	Global Effect	Direct Effect	Path Multiplier	Total Effect	Percent of Total	Total Percent
Hurbinf	Hrurag	Clive				0.225	0.001	2.109	0.002	0.9	0.9
Hurbinf	Cag	Aag	Clive				0.005	1.969	0.011	4.8	5.7
Hurbinf	Cman	Aman	Clive				0.053	1.76	0.093	41.3	47
Hurbinf	Cinf	Ainf	Clive				0.001	1.671	0.002	1.1	48.1
Hurbinf	Hrurag	Cman	Aman	Clive			0.001	2.615	0.003	1.2	49.3
Hurbinf	Hurbw	Cman	Aman	Clive			0.002	1.891	0.004	1.6	50.9
Hurbinf	Cag	Aag	Cman	Aman	Clive		0.001	2.462	0.004	1.6	52.5
Hurbinf	Cag	Aag	Flabn	Hrurag	Clive		0.001	2.554	0.004	1.6	54.1
Hurbinf	Cag	Aag	Flabn	Hrurpub	Clive		0.002	2.264	0.004	1.9	56
Hurbinf	Cinf	Ainf	Cman	Aman	Clive		0.007	2.122	0.014	6.3	62.3
Hurbinf	Cinf	Ainf	Flabn	Hrurag	Clive		0.001	2.65	0.001	0.6	62.9
Hurbinf	Cinf	Ainf	Flabn	Hrurpub	Clive		0.001	2.32	0.002	0.7	63.6
Hurbinf	Cserv	Aserv	Cman	Aman	Clive		0.002	2.78	0.007	2.9	66.5
Hurbcr	Hrurag	Clive				0.225	0.001	2.043	0.002	0.9	0.9
Hurbcr	Cag	Aag	Clive				0.002	1.949	0.004	1.8	2.7
Hurbcr	Cman	Aman	Clive				0.065	1.692	0.11	48.8	51.5
Hurbcr	Cinf	Ainf	Clive				0.002	1.607	0.003	1.4	52.9
Hurbcr	Hrurag	Cman	Aman	Clive			0.001	2.543	0.003	1.2	54.1
Hurbcr	Hurbw	Cman	Aman	Clive			0.002	1.822	0.004	1.6	55.6
Hurbcr	Cag	Aag	Cman	Aman	Clive		0.001	2.444	0.001	0.6	56.2
Hurbcr	Cag	Aag	Flabn	Hrurag	Clive		0.001	2.548	0.001	0.6	56.8
Hurbcr	Cag	Aag	Flabn	Hrurpub	Clive		0.001	2.259	0.002	0.7	57.6

cont.

Table 8. *Cont.d*

Path Target	<-Sect1	<-Sect2	<-Sect3	<-Sect4	<-Sect5	Global Effect	Direct Effect	Path Multiplier	Total Effect	Percent of Total	Total Percent
Hurbcr	Cinf	Ainf	Cman	Aman	Clive		0.009	2.053	0.018	8	65.5
Hurbcr	Cinf	Ainf	Flabn	Hrurag	Clive		0.001	2.642	0.002	0.8	66.4
Hurbcr	Cinf	Ainf	Flabn	Hrurpub	Clive		0.001	2.312	0.002	0.9	67.3
Hurbcr	Cserv	Aserv	Cman	Aman	Clive		0.003	2.705	0.008	3.4	70.6
Hurbw	Hrurag	Clive				0.215	0.001	2.111	0.002	0.8	0.8
Hurbw	Cag	Aag	Clive				0.006	1.997	0.012	5.6	6.4
Hurbw	Cman	Aman	Clive				0.046	1.751	0.081	37.5	44
Hurbw	Cinf	Ainf	Clive				0.001	1.674	0.002	1.1	45
Hurbw	Hrurag	Cman	Aman	Clive			0.001	2.633	0.002	1	46.1
Hurbw	Cag	Aag	Cman	Aman	Clive		0.002	2.511	0.004	1.9	48
Hurbw	Cag	Aag	Flabn	Hrurag	Clive		0.002	2.634	0.004	2	49.9
Hurbw	Cag	Aag	Flabn	Hrurpub	Clive		0.002	2.334	0.005	2.2	52.2
Hurbw	Cinf	Ainf	Cman	Aman	Clive		0.006	2.142	0.013	6.3	58.5
Hurbw	Cinf	Ainf	Flabn	Hrurpub	Clive		0.001	2.397	0.002	0.7	59.2
Hurbw	Cserv	Aserv	Cman	Aman	Clive		0.003	2.801	0.007	3.4	62.6
Hent	Cserv	Aserv	Cag	Aag	Clive	0.124	0.001	3.149	0.002	1.7	1.7
Hent	Cserv	Aserv	Cman	Aman	Clive		0.019	2.634	0.051	41.1	42.8
Hent	Cserv	Aserv	Fcapl	Hrurag	Clive		0.001	3.223	0.002	1.6	44.4
Hent	Cserv	Aserv	Flabp	Hrurpub	Clive		0.002	2.389	0.004	2.9	47.3
Hent	Cserv	Aserv	Flabn	Hrurag	Clive		0.001	3.609	0.005	4.1	51.3
Hent	Cserv	Aserv	Flabn	Hrurpub	Clive		0.002	3.194	0.006	4.6	55.9

Source: Model simulations using 2000 Chad SAM of Garber (2009). Account abbreviations are defined in table 6.

Long Term Impacts of Livestock Disease

Because of the relatively long and varied history of rinderpest control around the world, it is difficult to estimate the general contribution of eradication efforts. Also, countries have differing levels of livestock dependence as a percent of economic activity, and the domestic impact disease prevention may be magnified or offset by this. As the following figure for West Africa suggests, however, for low income countries livestock can be a very important contributor to formal sector income (Figure 8).

To give general indications of long-term impact of Rinderpest eradication on lower income economies, we use two types of forecasting models, one for a single country and a global model. The individual country is again Chad, as it is thought to represent a relatively livestock dependent low-income economy with reliable data. For the global model, we aggregate the GTAP 7 database to detail 19 regions and 12 sectors.

In both cases, the counterfactual for a world without Rinderpest eradication is necessary artificial, but we believe these results make clear both the absolute and relative vulnerability of lower income countries to recurrent incidence of such animal diseases. Using an elasticity scenario, we assume that livestock productivity in the counterfactual declines 1 percent annually, and then examine changes in annual macroeconomic aggregates over a twenty-year period (2010-2030). Data constraints prevent of from doing historical counterfactuals, but the pattern of vulnerabilities is thought to be representative of today's livelihood and livestock economy conditions.

Table 10 presents results for average annual changes in Chad's real macroeconomic aggregates under two scenarios designed to be indicative of recurrent livestock disease like Rinderpest:

1. Livestock sector productivity declines 1percent annually from 2010 to 2030.
2. Because of endemic disease burdens (repeat the above two scenarios), we assume Chadian livestock exports are reduced by 50 percent.

These results show how important livestock production is across the Chadian economy, but particularly for household livelihoods and purchasing power. If Livestock productivity sustained just 1 percent annual declines, as might result from the mortality and stunting associated with endemic Rinderpest, over two decades national income would be 15 percent lower, real consumption 17 percent lower, driving many vulnerable poor families over the threshold to destitution and malnutrition. If trade partners reacted to the disease emergence, as they often do, by restricting trade in livestock products, the adverse effects would be even more serious.

Real output results suggest the structural adjustments that would ensue from livestock sector linkages across the economy. For example, as a competitor for agricultural resources, Cotton is the only sector to benefit from livestock disease. Manufacturing, with a large component of food processing, is particularly hard hit, as are tertiary sectors with strong links to household final demand. Even the energy sector is hit by reduced aggregate growth. Analogous results would doubtless be obtained by assessments of other livestock dependent low-income countries, elsewhere in Africa and globally.

Table 9. Simulated economywide impacts of rinderpest control in 2000, billion CFA (2000 prices)

Account name	Change in final demand from no rinderpest control	Change in 2000 output from no rinderpest control	Original 2000 output (with rinderpest control)	2000 output with no rinderpest control	% change
Aag	0.00	-3.55	205.18	201.63	-1.73 %
Aagcot	0.00	0.00	27.04	27.04	0.00 %
Alive	-0.75	-1.89	190.54	188.65	-0.99 %
Afish	0.00	-0.32	36.67	36.35	-0.88 %
Aman	0.00	-1.66	164.69	163.03	-1.01 %
Acot	0.00	0.00	38.21	38.21	0.00 %
Adev	0.00	0.00	18.19	18.19	0.00 %
Acon	0.00	-0.06	57.38	57.32	-0.10 %
Ainf	0.00	-1.71	117.28	115.58	-1.46 %
Aserv	0.00	-5.29	532.34	527.05	-0.99 %
Agov	0.00	0.59	191.07	191.66	0.31 %
Cag	0.00	-4.77	275.50	270.73	-1.73 %
Cagcot	0.00	0.00	27.69	27.69	0.00 %
Clive	0.00	-1.21	202.77	201.56	-0.60 %
Cfish	0.00	-0.42	48.04	47.61	-0.88 %
Cman	0.00	-4.98	493.67	488.69	-1.01 %
Ccot	0.00	0.00	39.09	39.09	0.00 %
Cdev	0.00	0.00	18.62	18.62	0.00 %
Ccon	0.00	-0.06	58.76	58.70	-0.10 %
Cinf	0.00	-1.75	120.15	118.40	-1.46 %
Cserv	0.00	-7.04	708.52	701.49	-0.99 %
Cgov	0.64	0.61	195.48	196.08	0.31 %
Fland	0.00	-0.92	80.08	79.16	-1.14 %
Fcapf	0.00	-0.38	97.29	96.92	-0.39 %
Fcapl	0.00	-2.04	196.43	194.39	-1.04 %
Flabp	0.00	-0.12	79.96	79.83	-0.16 %
Flabn	0.00	-5.63	500.34	494.71	-1.12 %
Hrurag	-4.88	-9.27	358.99	349.72	-2.58 %
Hrurpub	0.01	-0.55	70.57	70.02	-0.78 %
Hurbinf	0.00	-1.00	90.79	89.79	-1.11 %
Hurbcr	0.00	-0.64	58.27	57.63	-1.11 %
Hurbpub	0.02	-0.90	113.88	112.97	-0.79 %
Hurbw	0.01	-0.46	66.35	65.88	-0.70 %
Hent	0.01	-2.06	241.39	239.33	-0.85 %

Source: Simulations using the Chad SAM of Garber (2009)

Next we examine the same issue globally, using a GTAP-based dynamic CGE model to examine two counterfactual scenarios:

1. Livestock sector productivity declines 1 percent annually from 2010 to 2030, in low-income countries only.

Figure 8. National livestock dependence, West Africa

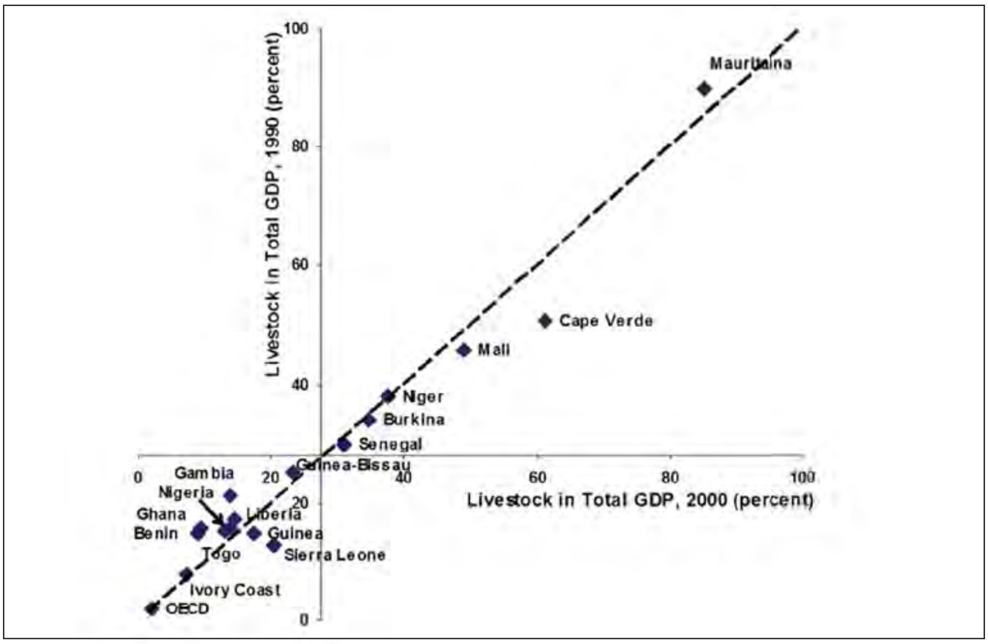


Table 10. Macroeconomic impacts of livestock sector scenarios for Chad (percentage change from Baseline values in 2030)

	Productivity	+ Export Loss
Real GDP	-15%	-14%
HH Income	-15%	-18%
Consumption	-17%	-19%
Exports	-11%	-9%
Imports	-7%	-9%
Real Output		
Agriculture	-6%	-6%
Cotton crops	2%	3%
Livestock	-27%	-28%
Fisheries	-6%	-5%
Manufacturing	-28%	-24%
Cotton Fib Mfg	2%	3%
Oil development	-5%	-3%
Construction	-8%	-7%
Informal Mfg	-21%	-21%
Services	-13%	-12%
Government	-2%	-2%

2. The same scenario including similar declines in Meat and Dairy sector productivity.

Results are generally more moderate from a global perspective (Table 11). The main reason for this is our assumption that higher income countries can fight livestock disease more effectively and help underwrite global food security. Even in this relatively optimistic situation, however, we see that many developing countries experience significant real income shocks from even low levels of livestock losses stemming from endemic diseases. Percentage changes in livestock productivity had greater than unit impacts on overall national income growth if they are sustained. Livestock is not merely a strategic agricultural sector, but an essential source of food and services to poor majorities, and thus livestock health represents and essential growth and livelihood resource for these countries.

To see these impacts from a sector perspective, the next table shows scenario output impacts for one of the most adversely affected regional economies, West Africa (Table 12). Here we see adjustments similar to Chad, but the disaggregated meat processing and dairy sectors are hit twice by productivity losses upstream and in their own operations. The latter can be thought to arise from SPS measures and other escalated costs of quality assurance. In any case, the general adjustment pattern that emerges is similar to the Chadian case, where strong adverse impacts on livestock reverberate widely across supply and expenditure chains, exerting a significant drag on economic progress.

India

Rinderpest in India has a long history, ravaging the livestock sector throughout the 18th and 19th century (Khera, 1979). Control efforts began in earnest during the 1930s, with the development of goat-attenuated vaccines, though their impact on mortality was relatively limited (Roeder and Rich, 2009). As shown in Table 13, annual mortality rates associated with rinderpest prior to 1954 (the start of the National Project on Rinderpest Eradication, or NPRE) often exceeded 200 000 bovines. In 1954, the NPRE commenced as a pilot project in 18 states, and was expanded nationwide in 1956-57 in all states, except Karnataka, Tamil Nadu, and Kerala (Nair, 1991). The goal of the NPRE was the vaccination of 80 percent of the cattle and buffalo population over a five-year period, with vaccination efforts

Table 11. Real GDP impacts of global livestock sector scenarios
(percent change from Baseline values in 2030)

Country / Region	Livestock	+Meat&Dairy
Sub-Saharan Africa	-0.7%	-1.5%
East Africa	-1.6%	-3.3%
West Africa	-2.1%	-4.4%
Mideast, N Africa	-0.8%	-1.8%
Bangladesh	-0.5%	-1.2%
India	-0.9%	-2.0%
Sri Lanka	-0.5%	-1.0%
Pakistan	-3.0%	-6.3%
ASEAN	-0.7%	-1.4%
High Income Asia	0.0%	-0.1%
PRC	-1.4%	-2.9%
Latin America	-0.7%	-1.5%
Mexico	-0.9%	-1.9%
Eastern Europe	-0.9%	-1.9%
European Union (27)	0.0%	-0.1%
Canada	-0.1%	-0.1%
United States	0.0%	-0.1%

Table 12. Output impacts of livestock sector scenarios for West Africa (percentage change from Baseline values in 2030)

Sector	Livestock	+Meat&Dairy
Crops	-1.2%	-2.3%
Livestock	-12.8%	-24.6%
Other Agric	-1.1%	-2.0%
Energy	-0.5%	-1.1%
Meat&Dairy	-32.9%	-57.3%
Textile&Apparel	-1.8%	-4.1%
Light Mfg	-0.8%	-1.8%
Heavy Mfg	-0.4%	-0.9%
Utility	-1.1%	-2.3%
Trade&Transport	-1.1%	-2.2%
Other Services	-1.4%	-3.1%

the remit of individual states (Roeder and Rich, 2009). Such control efforts were successful in reducing the number of outbreaks from over 8 000 in 1956 to just 295 by 1964 (Khera, 1979). While a number of states in the Northern and Eastern parts of the country were successful in controlling rinderpest through the NPRE, it re-emerged in previously free areas by the mid-1960s. Consequently, vaccination was started in these states for a 10-year period (Nair, 1991).

Control efforts in India included a combination of mass vaccination, movement control, surveillance zones, and buffer areas (Nair, 1991). Such efforts kept rinderpest outbreaks at a relative steady state during the 1970s and 1980s (Table 13), but were not able to fully eradicate the disease. In response, the NPRE designed an intensive three-year programme to increase vaccination coverage to 90 percent in endemic states and targeted vaccination as needed in others. This last push of efforts, funded through EU cooperation, helped India to become free from rinderpest in 1995 (Roeder and Rich, 2009).

Data on the costs of rinderpest eradication are limited. Information from the Government of India on budget allocations during the 1990s and 2000s reveals a total of 3.49 billion INR spent during 1992-2008 on rinderpest control, including 435 million INR per year during 1992-1998 for the last stages of eradication. The remaining funds were dedicated primarily to sero-surveillance and monitoring of bovine herds. Consistent data previous to 1992 were not available, and for the scenarios below, we simply considered the cost of vaccination (in constant 2 005 INR) of 55 INR per vaccination multiplied by the number of vaccinations provided from our data. This likely underestimates the cost aspects in our scenarios but at least provides a first approximation of the major costs associated with rinderpest control and eradication.

We considered three scenarios in the India case, applying the same methodology as before on the sector (i.e., use of DynMod to project alternative population structures based on mortality rates as below):

1. A mass vaccination vs. limited vaccination scenario: In this scenario, we looked at the actual rinderpest control programme compared with the counterfactual case in which there is less vaccination (and consequently higher levels of mortality and morbidity). We looked at the period 1972-1989 as it was the

Table 13. Rinderpest incidence and vaccination coverage in India, 1924-1996

Year	Bovines	Vaccinations	Outbreaks	Sick	Deaths	Deaths/1,000
1924	143 806 000	na	na	na	94 300	0.656
1925	144 711 000	na	na	na	155 000	1.071
1926	145 442 000	na	na	na	275 900	1.897
1927	146 173 000	na	na	na	202 000	1.382
1928	na	na	na	na	na	
1929	na	na	na	na	na	
1930	na	na	na	na	na	
1931	149 443 000	na	na	na	203 758	1.363
1932	150 519 000	na	na	na	182 441	1.212
1933	151 595 000	na	na	na	209 524	1.382
1934	152 677 000	na	na	na	179 877	1.178
1935	153 745 000	na	na	na	125 459	0.816
1936	152 518 000	na	na	na	135 251	0.887
1937	151 219 000	na	na	na	160 055	1.058
1938	150 064 000	na	na	na	89 700	0.598
1939	148 837 000	na	na	na	124 885	0.839
1940	na	na	na	na	na	
1941	na	na	na	na	na	
1942	na	na	na	na	na	
1943	na	na	na	na	na	
1944	na	na	na	na	na	
1945	na	na	na	na	na	
1946	na	na	na	na	na	
1947	na	na	na	na	na	
1948	na	na	na	na	na	
1949	na	na	na	na	na	
1950	na	na	8 000	400 000	200 000	
1951	na	na	8 000	na	na	
1952	na	na	8 000	na	na	
1953	na	na	8 000	na	na	
1954	na	na	8 000	na	na	
1955	na	2 000 000	8 000	na	na	
1956	na	3 780 000	8 000	na	na	
1957	na	5 580 000	8 156	60 002	27 387	
1958	na	14 570 000	6 196	93 744	40 772	
1959	na	25 730 000	7 720	41 185	11 261	
1960	na	27 370 000	2 449	13 242	4 732	
1961	226 807 920	22 370 000	960	16 441	6 242	0.028
1962	225 441 008	15 680 000	1 055	15 140	4 880	0.022
1963	225 326 016	20 460 000	504	5 550	2 640	0.012
1964	228 000 000	25 010 000	354	6 682	3 204	0.014
1965	228 440 000	22 050 000	295	5 938	2 246	0.010
1966	229 167 008	24 410 000	307	9 390	3 608	0.016

cont.

Table 13. *Cont.d*

Year	Bovines	Vaccinations	Outbreaks	Sick	Deaths	Deaths/1,000
1967	230 240 000	25 900 000	577	10 833	5 835	0.025
1968	231 340 016	26 030 000	870	7 185	2 487	0.011
1969	232 450 000	29 610 000	396	7 267	2 723	0.012
1970	233 560 000	33 190 000	374	6 140	2 571	0.011
1971	234 690 000	34 450 000	360	8 986	2 153	0.009
1972	235 810 000	44 200 000	207	2 710	1 532	0.006
1973	236 980 016	47 260 000	160	3 572	1 528	0.006
1974	238 140 000	44 090 000	195	3 342	1 627	0.007
1975	239 377 008	43 220 000	160	2 814	1 433	0.006
1976	241 280 000	51 550 000	161	4 314	2 630	0.011
1977	242 315 008	59 430 000	140	4 768	2 947	0.012
1978	245 322 000	50 970 000	143	2 662	1 146	0.005
1979	248 980 000	55 000 000	121	0	0	0.000
1980	252 570 000	56 600 000	183	0	0	0.000
1981	256 200 000	56 600 000	213	0	0	0.000
1982	262 237 008	56 600 000	127	2 295	691	0.003
1983	265 370 016	56 600 000	82	0	0	0.000
1984	268 550 000	56 600 000	121	0	0	0.000
1985	271 770 000	65 200 000	117	0	0	0.000
1986	275 050 016	65 200 000	175	na	2 503	0.009
1987	275 662 008	65 200 000	232	na	3 318	0.012
1988	278 120 000	65 200 000	321	na	4 590	0.017
1989	280 600 000	65 200 000	155	na	2 217	0.008
1990	283 070 000	na	126	na	1 802	0.006
1991	285 660 000	na	94	na	1 344	0.005
1992	288 790 000	na	96	na	1 373	0.005
1993	288 952 000	na	103	na	1 473	0.005
1994	289 128 000	na	29	na	415	0.001
1995	289 319 000	na	10	na	143	0.000
1996	289 525 000	na	0	0	0	0.000

Source: Compiled from data in Khera (1979); Nair (1991); and FAOSTAT.

earliest period in which complete production and price data were available from local and international sources (IMF, FAOSTAT). For this case, we assume that under limited vaccination, 10 075 million vaccinations were administered, equivalent to the average quantity used during the late 1950s before NPRE started in earnest. We further assumed an additional mortality rate associated with rinderpest of 0.0152 percent and morbidity rate of 0.0343 percent based on the 1957-58 average.

2. A mass vaccination vs. “no control” scenario: In this scenario, our counter-factual case is akin to the situation pre-independence in which mortality rates were much higher (0.1 percent per annum), as were morbidity rates (0.26 percent), based on averages prevailing in the 1920s-1940s. We further assume that vaccination coverage was limited to just 2 million doses per year.

3. Market access scenario, post-NPRE: The final scenario looked at the impact of NPRE on market access from the 1990s onward. In this case, we considered the period 1992-2007 and examined how trade effects with and without rinderpest control influenced its viability as a policy intervention. We assumed mortality and morbidity rates in the counterfactual as those prevailing in the 1980s and looked only at the additional costs associated with the final push in the 1990s to eradicate the disease. On the trade side, the counterfactual assumes that export growth was at 1980-89 average levels for buffalo meat (1.92 percent per annum) and 1990-91 average levels for cattle meat (2.16 percent per annum). The 1990-91 rates were used for cattle meat because exports during the 1980s were relatively small and difficult to associate with a defined trend until the end of the 1980s.

Table 14 summarizes the different scenarios. In the first scenario, the benefit-cost ratio of mass vaccination vis-à-vis limited vaccination was slightly less than 1 (0.98), suggesting that the mass vaccination programme of the 1970s and 1980s, compared to more limited programmes earlier, may not, *prima facie,* been a good investment. In particular, the high additional costs of vaccination initially dwarf relatively limited benefits from additional and small numbers of livestock resulting from greater rinderpest control (Figure 9). A couple of caveats temper the conclusion of this analysis, however. First, the cumulative impact of rinderpest control eventually outweighs the added costs, as Figure 9 illustrates, around 1980. A longer-term time perspective would likely increase the BCR in this scenario. Second, the analysis does not consider the multiplier impacts on other, non-livestock parts of the economy. While a SAM for India was not available for this analysis, Roeder and Rich (2009) estimated multipliers for the livestock sector in Africa and South Asia that ranged from 3-5, suggesting still positive benefits to rinderpest control. Finally, as noted in the sensitivity analysis discussed below, the BCR is highly sensitive to the assumption of mortality rates associated with rinderpest.

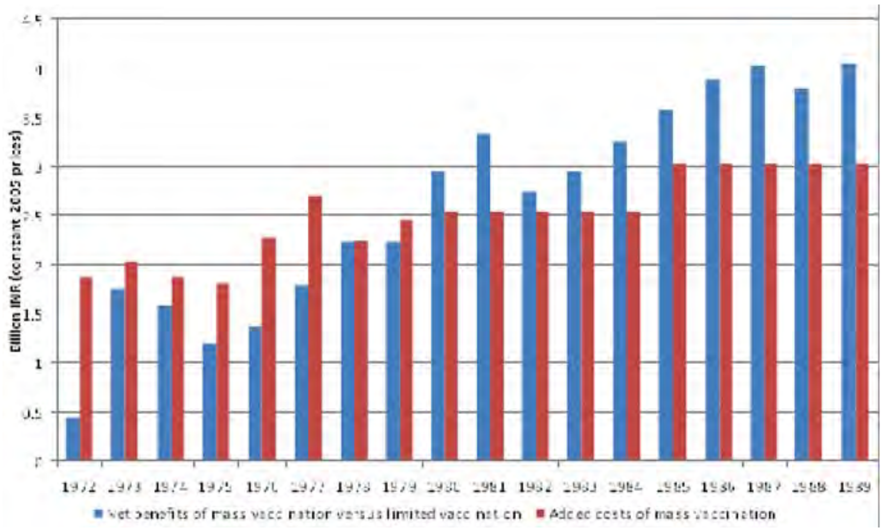
When compared to a scenario of no-control, the benefit-cost ratio of the mass vaccination programme becomes much higher (estimated at 5.42), with positive and large benefits relative to the additional costs (Figure 10). As above, this strongly depends on the assumed mortality rate associated with rinderpest. Figure 11 illustrates the results of sensitivity analysis in which the mortality rate associated with rinderpest was varied between 0.01 percent and 0.1 percent. The analysis demonstrates much higher BCRs as rinderpest-attributable mortality rises.

Table 14. Summary of Benefit-Cost Ratios of Differential Rinderpest Control Scenarios

Counterfactual scenario	Benefit-cost ratio
1) Limited vaccination during 1972-1989: annual vaccination of 10.075 million herds, mortality/moribidity rates of late 1950s	0.98
2) "No control" during 1972-1989: annual vaccination of 2 million herds; mortality/morbidity rates of 1920s-1940s	5.42
3) No eradication in 1990s: control patterns and market access for bovine meat based on 1980s	64.77

Source: Simulations with DynMod

Figure 9. Added benefits and costs associated with mass vaccination versus limited vaccination in India, 1972-1989.

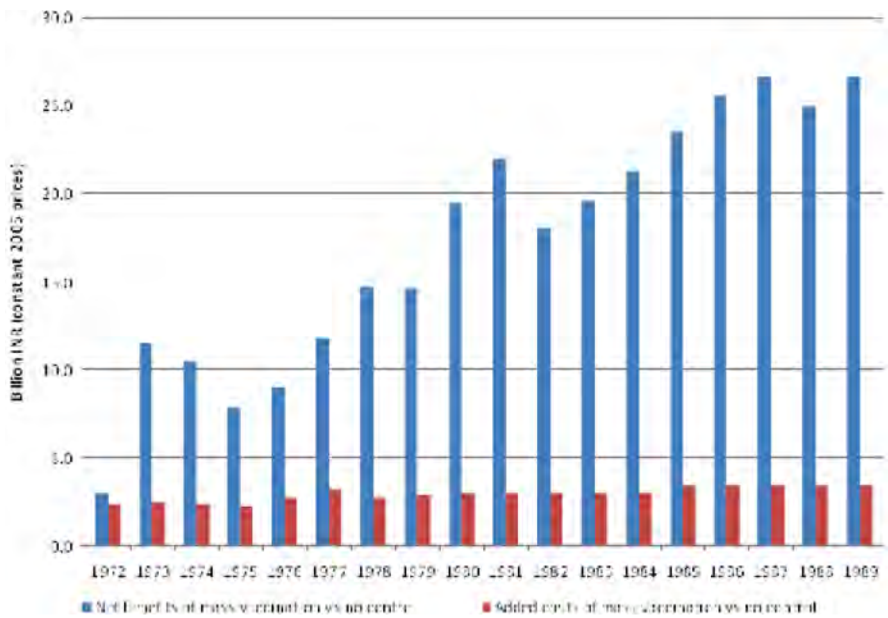


Source: Model simulations with DynMod.

Finally, when we consider the final eradication of rinderpest in the 1990s under the NPRE, we observe a huge success from the standpoint of its BCR (well over 64, see Table 14). The large size of this BCR is fueled by much higher market access (a more than six-fold increase in volume terms) for livestock exports that boomed as rinderpest freedom was achieved (Figure 12).

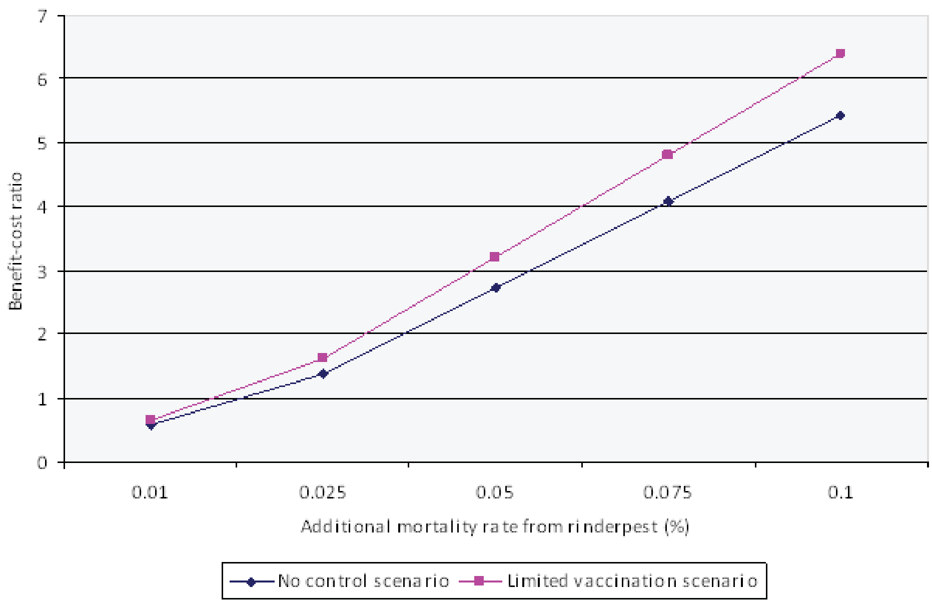
To assess rinderpest control in an economywide framework, we developed a new Social Accounting Matrix (SAM) for India, updating detailed industry accounts and household expenditure survey data to reflect the structure of the economy in 2008 (see Table 15). The resulting table supports the same multiplier estimation and decomposition analysis carried out for Chad. These results are interesting in their own right and for comparison. One valuable property of the Indian input-output data is an activity account for Animal Services, which are primarily comprised of animal traction. This account was included in the Indian SAM for reasons that should be more widely recognized, especially in Asia and Africa. Although meat consumption at the village level is limited (particularly in India), the services of animal traction are part of the bedrock of local economic activity, not only in farm production but in commercial distribution and other transport services. Moreover, this service would be quite sensitive to bovine health status, and as such offers an important assessment metric for rinderpest damages. As can be seen in Table 16, multipliers from Animal Services are large and widely dispersed across stakeholders in the Indian economy, reflecting the importance of animal traction in the small holder agrofood supply chain and that supply chain's pervasive linkages across the Indian economy. Table 17 provides more focused results, showing only the household income multipliers arising from livestock activities. It is noteworthy that animal services have the largest impact across this category of agriculture, both for households generally and across the Indian economy. These results contrast sharply with a long literature on valuing animal traction (e.g. Binswanger *et al.*, 1982). We be-

Figure 10. Added benefits and costs associated with mass vaccination versus no control in India, 1972-1989.



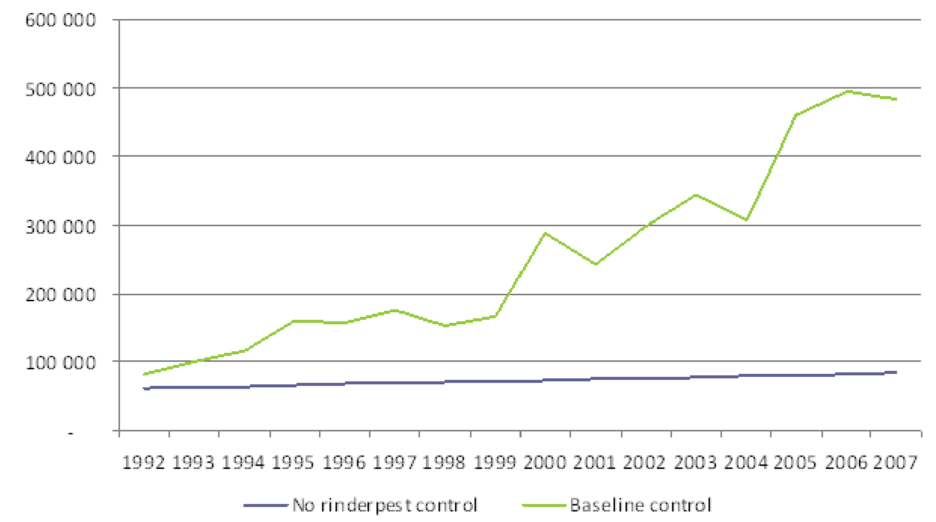
Source: Model simulations with DynMod.

Figure 11. Sensitivity analysis of benefit-cost ratio eradication in India, based on different mortality rates.



Source: Model simulations with DynMod.

Figure 12. Changes in bovine meat exports associated with rinderpest control and "no control" scenario, 1992-2007.



Source: Model simulations with DynMod.

lieve those studies to be biased downward because of their emphasis on valuing the animals (as capital goods) rather than valuation of their services. Even those studies that take a cost-benefit approach that attributes direct production or transport service income to animals will understate their contribution to economywide income.

The next step with the Indian SAM is to decompose household income effects that originate from livestock, their products, and services. Because the Indian SAM details income by locality and employment status, we can better understand the pervasive nature of livestock's contribution to domestic livelihoods. Table 18 details the path decomposition of each livestock activity on each household group. There are many details here, but a few salient aspects deserve emphasis. As would be expected, rural households gain most from livestock activities, with the poorest (labourer households) gaining more than rural enterprise households. These pro-rural and pro-poor effects reveal the important of smallholder livestock to national livelihood promotion. As the livestock and livestock products sectors continue modernization, it is essential that supporting rural policies work to sustain this source of income for rural poor majorities.

Closer inspection of the decomposition results shows the potency of market access in the livestock-livelihood pathway. For every household type, the secondary agent in income effects from the cattle/milk sector (AMLK) is food processing (APFD), an activity that requires market access and (for many poor in India) the animal services to achieve this. For all rural households and a few (low income) urban ones, we also see the second largest source of livestock generated income is income attributed to animal (traction) services in rice production.

To place livestock and animal health assessment in a long-term context, we now follow the example of the Chad assessment and apply a dynamic CGE forecasting tool to our data for India. The macroeconomic impacts of the same two scenarios (falling livestock productivity and export disruption) are summarized in Table 19 and

Table 15. Institutions of the 2008 India SAM

1	Paddy Rice	CPAD	**42**	Construction	CCON
2	Wheat	CWHT	**43**	Road Vehicle Transport	CVTP
3	Cereals,Grains etc,Other crops	CCER	**44**	Rail Transport	CRTP
			45	Air Transport	CATP
4	Sugar Cane	CSGR	**46**	Water Transport	CWTP
5	Oilseeds	COSD	**47**	Health & medical	CHLM
6	Cash crops	CCAS	**48**	Communication	CCOM
7	Cattle Meat and Milk	CMLK	**49**	Trade	CTRD
8	AnimalServ	CANS	**50**	All other services	CSER
9	PoultryEgg	CPOL	**51**	Skilled Labor	LABSK
10	OthLvstk	CLVS	**52**	Capital	CAP
11	Forestry	CFRS	**53**	Land	LAN
12	Fishing	CFSH	**54**	Rural Nonag Self Employed	RNagSE
13	Coal	CCOL	**55**	Rural Ag Laborers	RAgLab
14	Petroleum	COIL	**56**	Rural Other Laborers	ROthLab
15	Gas Manufacture & Distribution	CGAS	**57**	Rural Ag Self Employed	RAgSE
			58	Rural Other Households	ROthHH
16	Food & beverages	CPFD	**59**	Urban Self Employed	USE
17	Animal Textiles	CATX	**60**	Urban Salaried Workers	USal
18	Other Textiles	COTX	**61**	Urban Casual Labor	UCasLab
19	Apparel	CAPR	**62**	Urban Other Households	UOthHH
20	Leather	CLEA	**63**	Private Enterprises	PvtEnt
21	Wood	CLUM	**64**	Public Enterprises	PubEnt
22	Mineral Products	CNMM	**65**	Government	GOV
23	Refined Petroleum and Coal Products	CPET	**66**	Indirect Taxes	ITX
24	Chemicals	CCRP	**67**	Trade Taxes	TTX
25	AgroChem	CACH	**68**	Direct Taxes	DTX
26	Pharma and Cosmetics	CPCH	**69**	Capital Account	CAC
27	Paper & Paper prod.	CPPP	**70**	Rest of World	ROW
28	IronSteel	CI_S			
29	NonFerMetals	CNFM			
30	Cement	CCEM			
31	Aluminium	CALU			
32	Other manufacturing	COMF			
33	Machinery	COME			
34	Electronic Machinery	CELC			
35	Cars and Trucks	CMVH			
36	Bikes and Cycles	CBVH			
37	Aircraft	CAVH			
38	Rail Vehicles	CRVH			
39	Ships	CWVH			
40	Conventional Electric Power	CELE			
41	Water	CWAT			

Table 16. Agricultural activity multipliers for the India SAM

		APAD	AWHT	ACER	ASGR	AOSD	ACAS	AMLK	AANS	APOL	ALVS
Activities	Paddy Rice	1.49	0.11	0.09	0.10	0.08	0.11	0.07	0.09	0.12	0.08
	Wheat	0.06	1.61	0.07	0.06	0.05	0.08	0.05	0.07	0.04	0.05
	Cereals,Grains etc, Other crops	0.05	0.07	1.20	0.05	0.04	0.05	0.04	0.06	0.10	0.05
	Sugar Cane	0.02	0.02	0.02	1.21	0.02	0.02	0.02	0.02	0.01	0.02
	Oilseeds	0.03	0.04	0.03	0.03	1.09	0.03	0.03	0.03	0.03	0.03
	Cash crops	0.19	0.20	0.21	0.19	0.19	1.23	0.22	0.67	0.14	0.36
	Cattle Meat and Milk	0.08	0.10	0.08	0.09	0.08	0.09	1.07	0.08	0.07	0.07
	AnimalServ	0.07	0.04	0.12	0.04	0.08	0.04	0.01	1.03	0.02	0.02
	PoultryEgg	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	1.01	0.01
	OthLvstk	0.04	0.03	0.04	0.03	0.04	0.03	0.02	0.02	0.02	1.02
	Forestry	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Fishing	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Coal	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	Petroleum	0.10	0.11	0.08	0.08	0.07	0.07	0.05	0.07	0.05	0.06
	Gas Manufacture & Dist	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00
	Food & beverages	0.19	0.22	0.18	0.21	0.18	0.19	0.17	0.24	0.18	0.19
	Animal Textiles	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Other Textiles	0.06	0.07	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.05
	Apparel	0.03	0.04	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03
	Leather	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Wood	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Mineral Products	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
	Refined Petroleum and Coal	0.17	0.19	0.15	0.15	0.14	0.13	0.09	0.13	0.09	0.11
	Chemicals	0.12	0.14	0.09	0.11	0.10	0.09	0.07	0.09	0.07	0.08
	AgroChem	0.15	0.20	0.09	0.13	0.10	0.09	0.03	0.06	0.03	0.04
	Pharma and Cosmetics	0.04	0.04	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.03
	Paper & Paper prod.	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.02
	IronSteel	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.01
	NonFerMetals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cement	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Aluminium	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Other manufacturing	0.04	0.05	0.04	0.04	0.04	0.04	0.03	0.04	0.03	0.03
	Machinery	0.02	0.03	0.03	0.02	0.02	0.02	0.01	0.02	0.02	0.02
	Electronic Machinery	0.04	0.04	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03

cont.

Table 16. *Cont.d*

		APAD	AWHT	ACER	ASGR	AOSD	ACAS	AMLK	AANS	APOL	ALVS
Activities	Ships	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Conventional Electric Power	0.12	0.14	0.07	0.09	0.07	0.07	0.05	0.07	0.05	0.05
	Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Construction	0.04	0.05	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.02
	Road Vehicle Transport	0.22	0.25	0.20	0.22	0.19	0.19	0.16	0.25	0.15	0.19
	Cars and Trucks	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01
	Bikes and Cycles	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Aircraft	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Rail Vehicles	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Rail Transport	0.03	0.04	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
	Air Transport	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
	Water Transport	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Health & medical	0.05	0.05	0.04	0.05	0.04	0.05	0.04	0.04	0.04	0.04
	Communication	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.02
	Trade	0.33	0.38	0.30	0.29	0.27	0.26	0.26	0.57	0.22	0.36
	All other services	0.44	0.50	0.39	0.47	0.40	0.41	0.35	0.41	0.34	0.36
Total for Activities		4.48	5.09	3.92	4.13	3.73	3.70	3.21	4.48	3.17	3.58
Factors	Skilled Labor	1.14	1.33	1.06	1.27	1.10	1.15	1.05	1.03	1.06	1.03
	Capital	0.72	0.84	0.62	0.71	0.62	0.62	0.82	0.72	0.83	0.78
	Land	0.34	0.40	0.34	0.44	0.38	0.41	0.10	0.24	0.10	0.15
Total for Factors		2.20	2.58	2.03	2.42	2.10	2.19	1.98	1.99	1.98	1.95
Household	Rural Nonag Self Employed	0.15	0.17	0.14	0.16	0.14	0.14	0.15	0.14	0.15	0.14
	Rural Ag Laborers	0.18	0.21	0.17	0.20	0.18	0.18	0.17	0.16	0.17	0.16
	Rural Other Laborers	0.06	0.07	0.05	0.07	0.06	0.06	0.06	0.05	0.06	0.05
	Rural Ag Self Employed	0.64	0.75	0.61	0.75	0.65	0.69	0.41	0.52	0.40	0.44
	Rural Other Households	0.12	0.14	0.11	0.12	0.11	0.11	0.13	0.12	0.13	0.12
	Urban Self Employed	0.21	0.24	0.19	0.22	0.19	0.19	0.21	0.19	0.21	0.20
	Urban Salaried Workers	0.44	0.51	0.40	0.48	0.42	0.44	0.41	0.39	0.41	0.40
	Urban Casual Labor	0.07	0.08	0.06	0.07	0.06	0.07	0.06	0.06	0.06	0.06
	Urban Other Households	0.04	0.05	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.04
Total for Households		1.90	2.22	1.77	2.12	1.84	1.92	1.64	1.69	1.64	1.63
Grand Total		8.59	9.89	7.72	8.67	7.67	7.81	6.83	8.15	6.79	7.17

Table 17. Household livestock multipliers

	AMLK	AANS	APOL	ALVS
Rural Nonag Self Employed	0.15	0.14	0.15	0.14
Rural Ag Labourers	0.17	0.16	0.17	0.16
Rural Other Labourers	0.06	0.05	0.06	0.05
Rural Ag Self Employed	0.41	0.52	0.40	0.44
Rural Other Households	0.13	0.12	0.13	0.12
Urban Self Employed	0.21	0.19	0.21	0.20
Urban Salaried Workers	0.41	0.39	0.41	0.40
Urban Casual Labourers	0.06	0.06	0.06	0.06
Urban Other Households	0.05	0.04	0.05	0.04
Total for Households	1.64	1.69	1.64	1.63
Grand Total	**6.83**	**8.15**	**6.79**	**7.17**

Table 18. Path decomposition for households in India

Path Target	<-Sect1	<-Sect2	<-Sect3	<-Sect4	<-Sect5	Global Effect	Direct Effect	Path Multiplier	Total Effect	Percent of Total	Total Percent
RNagSE	AMLK					0.079	0.036	1.143	0.041	52	52
RNagSE	APFD	AMLK					0.004	1.414	0.005	6	59
RNagSE	ACAS	LAN	RAgSE	AMLK			0.001	1.585	0.001	1	60
RNagSE	APAD	AANS				0.014	0.001	1.624	0.002	15	15
RNagSE	ACER	AANS					0.001	1.312	0.002	14	28
RNagSE	ACAS	AANS					0.001	1.314	0.002	12	40
RNagSE	APOL					0.010	0.004	1.085	0.005	48	48
RNagSE	ALVS					0.022	0.008	1.098	0.009	40	40
RNagSE	APFD	ALVS					0.001	1.370	0.001	4	44
RAgLab	AMLK					0.114	0.044	1.203	0.053	47	47
RAgLab	APFD	AMLK					0.006	1.471	0.009	8	55
RAgLab	ACAS	LAN	RAgSE	AMLK			0.001	1.631	0.002	2	57
RAgLab	ASER	LABSK	USal	AMLK			0.001	1.934	0.001	1	57
RAgLab	APAD	AANS				0.024	0.002	1.702	0.004	17	17
RAgLab	ACER	AANS					0.003	1.381	0.004	15	33
RAgLab	AOSD	AANS					0.001	1.266	0.001	4	37
RAgLab	ACAS	AANS					0.002	1.364	0.003	14	51
RAgLab	APFD	AOSD	AANS				0.001	1.542	0.001	4	55
RAgLab	APOL					0.014	0.005	1.148	0.006	43	43
RAgLab	ASER	APOL					0.001	1.532	0.001	6	49
RAgLab	ALVS					0.033	0.010	1.160	0.012	35	35
RAgLab	APAD	ALVS					0.001	1.692	0.001	4	39
RAgLab	APFD	ALVS					0.001	1.428	0.001	4	43
RAgLab	ALEA	ALVS					0.001	1.408	0.001	2	46
ROthLab	AMLK					0.120	0.052	1.114	0.057	48	48
ROthLab	APFD	AMLK					0.006	1.386	0.008	7	55
ROthLab	ASER	AMLK					0.001	1.513	0.001	1	55
ROthLab	ACAS	LAN	RAgSE	AMLK			0.001	1.556	0.002	1	57
ROthLab	ASER	LABSK	USal	AMLK			0.001	1.935	0.001	1	58
ROthLab	ASER	CAP	RAgSE	AMLK			0.001	1.857	0.001	1	59
ROthLab	APAD	AANS				0.021	0.002	1.581	0.003	14	14
ROthLab	ACER	AANS					0.002	1.276	0.003	13	27
ROthLab	AOSD	AANS					0.001	1.169	0.001	3	30

cont.

Table 18. *Cont.d*

Path Target	<-Sect1	<-Sect2	<-Sect3	<-Sect4	<-Sect5	Global Effect	Direct Effect	Path Multiplier	Total Effect	Percent of Total	Total Percent
ROthLab	ACAS	AANS					0.002	1.283	0.002	11	42
ROthLab	APFD	AOSD	AANS				0.001	1.448	0.001	4	46
ROthLab	APOL					0.015	0.006	1.054	0.006	44	44
ROthLab	ASER	APOL					0.001	1.447	0.001	6	50
ROthLab	ALVS					0.034	0.012	1.067	0.012	36	36
ROthLab	APAD	ALVS					0.001	1.574	0.001	3	39
ROthLab	APFD	ALVS					0.001	1.339	0.001	4	43
ROthLab	ALEA	ALVS					0.001	1.296	0.001	2	45
RAgSE	AMLK					0.095	0.045	1.336	0.060	63	63
RAgSE	APFD	AMLK					0.004	1.599	0.006	6	70
RAgSE	APAD	AANS				0.015	0.001	1.881	0.002	16	16
RAgSE	ACER	AANS					0.001	1.536	0.002	14	31
RAgSE	ACAS	AANS					0.001	1.470	0.002	13	43
RAgSE	APOL					0.012	0.005	1.289	0.007	59	59
RAgSE	ALVS					0.027	0.010	1.299	0.013	50	50
RAgSE	APFD	ALVS					0.001	1.563	0.001	4	53
ROthHH	AMLK					0.087	0.039	1.143	0.045	52	52
ROthHH	APFD	AMLK					0.004	1.416	0.005	6	57
ROthHH	ACAS	LAN	RAgSE	AMLK			0.001	1.590	0.001	1	58
ROthHH	ASER	LABSK	USal	AMLK			0.001	1.968	0.001	1	60
ROthHH	ASER	CAP	RAgSE	AMLK			0.001	1.840	0.001	1	61
ROthHH	APAD	AANS				0.014	0.001	1.627	0.002	12	12
ROthHH	ACER	AANS					0.001	1.313	0.002	13	24
ROthHH	ACAS	AANS					0.001	1.319	0.001	10	34
ROthHH	APOL					0.011	0.005	1.085	0.005	47	47
ROthHH	ASER	APOL					0.001	1.465	0.001	7	54
ROthHH	ALVS					0.024	0.009	1.098	0.010	40	40
ROthHH	APFD	ALVS					0.001	1.371	0.001	3	43
USE	AMLK					0.088	0.042	1.183	0.049	56	56
USE	APFD	AMLK					0.003	1.457	0.005	5	62
USE	ASER	AMLK					0.001	1.556	0.001	1	62
USE	ASER	LABSK	USal	AMLK			0.001	1.970	0.001	1	64
USE	ASER	CAP	RAgSE	AMLK			0.001	1.865	0.001	1	65
USE	APAD	AANS				0.012	0.001	1.687	0.001	11	11
USE	ACER	AANS					0.001	1.363	0.002	14	24
USE	ACAS	AANS					0.001	1.363	0.001	9	33
USE	APOL					0.011	0.005	1.128	0.006	51	51
USE	ASER	APOL					0.001	1.496	0.001	8	59
USE	ALVS					0.024	0.009	1.141	0.011	44	44
USE	APFD	ALVS					0.001	1.415	0.001	3	47
USal	AMLK					0.068	0.028	1.262	0.035	52	52
USal	APFD	AMLK					0.002	1.541	0.003	5	57
USal	ASER	AMLK					0.001	1.606	0.001	1	58
USal	ASER	CAP	RAgSE	AMLK			0.001	1.945	0.001	2	60
USal	ACER	AANS				0.010	0.001	1.457	0.001	12	12
USal	APOL					0.009	0.003	1.210	0.004	46	46
USal	ASER	APOL					0.001	1.549	0.001	12	57

cont.

Table 18. *Cont.d*

Path Target	<-Sect1	<-Sect2	<-Sect3	<-Sect4	<-Sect5	Global Effect	Direct Effect	Path Multiplier	Total Effect	Percent of Total	Total Percent
USal	ALVS					0.019	0.006	1.222	0.008	41	41
UCasLab	AMLK					0.078	0.033	1.104	0.036	46	46
UCasLab	APFD	AMLK					0.004	1.377	0.005	7	53
UCasLab	ACAS	LAN	RAgSE	AMLK			0.001	1.548	0.001	1	54
UCasLab	ASER	LABSK	USal	AMLK			0.001	1.936	0.001	1	55
UCasLab	APAD	AANS				0.013	0.001	1.568	0.002	12	12
UCasLab	ACER	AANS					0.001	1.264	0.002	13	25
UCasLab	ACAS	AANS					0.001	1.274	0.001	10	35
UCasLab	APOL					0.010	0.004	1.043	0.004	42	42
UCasLab	ASER	APOL					0.001	1.437	0.001	8	49
UCasLab	ALVS					0.022	0.007	1.056	0.008	35	35
UCasLab	APFD	ALVS					0.001	1.329	0.001	4	39
UOthHH	AMLK					0.073	0.028	1.099	0.031	42	42
UOthHH	APFD	AMLK					0.002	1.373	0.003	4	46
UOthHH	ASER	AMLK					0.001	1.496	0.001	1	48
UOthHH	ASER	LABSK	RAgLab	AMLK			0.001	1.938	0.001	1	49
UOthHH	ASER	LABSK	USal	AMLK			0.001	1.945	0.001	2	51
UOthHH	ASER	CAP	RAgSE	AMLK			0.001	1.829	0.001	2	53
UOthHH	ACER	AANS				0.011	0.001	1.257	0.001	10	10
UOthHH	APOL					0.009	0.003	1.037	0.003	36	36
UOthHH	ASER	APOL					0.001	1.428	0.001	11	47
UOthHH	ALVS					0.020	0.006	1.050	0.007	32	32

Table 20. Generally speaking, the results are analogous, after discounting for the relatively smaller role of livestock in Indian GDP, all macroeconomic impacts are signed in the same adverse direction. Moreover, we see again that, in the long run, the export disruption has a minimal effect because of resource and activity substitution. The same annual productivity decline has a less pronounced effect on Indian livestock output, probably because there are more alternative economic activities for resource re-allocation and demand for livestock products is more price and income elastic.

Because the India SAM was build with detailed household survey data, we can gain valuable insight about the incidence of adverse livestock events like Rinderpest. Table 20 reveals two important general facts. Firstly, as was apparent in the macro results of Table 19, household real consumption falls more than household real income because the adverse price impacts are on staple commodities with limited substitution possibilities.[3] This fact reminds us of a universal truth – the poor are by necessity extremely sensitive to food prices. In fact, about half of humanity has to spend half their income on food and, because these are predominately local staple foods, substitution possibilities for them are limited. The adverse staple food price cycle in 2007-2008 gave ample evidence of this, with riots in a dozen countries. In practical terms, what could be called the Half-Half Rule means that agricultural productivity, whether in livestock or other food sectors, is a critical strategic issue for social welfare and stability.

[3] Following convention for welfare assessment in low-income countries, we focus on household expenditure and real consumption rather than income.

Table 19. Macroeconomic impacts of livestock sector scenarios for India (Percent change from baseline values in 2030)

	Productivity	+ Export Loss
Real GDP	-6%	-7%
HH Income	-3%	-3%
Consumption	-8%	-8%
Exports	-5%	-5%
Imports	-5%	-6%
Output		
Paddy Rice	-1%	-1%
Wheat	-2%	-2%
Cereals, Grains etc.	-1%	-1%
Sugar Cane	-3%	-3%
Oilseeds	-2%	-2%
Cash crops	-2%	-2%
Milk	-34%	-34%
Animal Services	-2%	-2%
Poultry&Eggs	-3%	-4%
Other Livestock	-21%	-22%
Forestry	-4%	-4%
Fishing	-4%	-4%
Coal	-4%	-4%
Petroleum	-5%	-5%
Gas Manufacture & Distribution	-4%	-4%
Food & beverages	-3%	-3%
Animal Textiles	-8%	-8%
Other Textiles	-1%	-1%
Apparel	-2%	-2%
Leather	-19%	-20%
Wood	-4%	-4%
Mineral Products	-2%	-2%
Refined Petroleum and Coal Products	-4%	-4%
Chemicals	-3%	-3%
Agro Chemicals	-2%	-2%
Pharma and Cosmetics	-4%	-4%
Paper & Paper prod.	-4%	-4%
Iron&Steel	-4%	-4%
NonFerrous Metals	-5%	-5%
Cement	-4%	-4%
Aluminum	-5%	-5%
Other manufacturing	-4%	-4%
Machinery	-4%	-4%
Electronic Machinery	-4%	-4%
Cars and Trucks	-4%	-4%
Bikes and Cycles	-4%	-4%
Aircraft	-5%	-5%
Rail Vehicles	-4%	-4%
Conventional Electric Power	-4%	-4%
Water	-3%	-3%
Construction	-4%	-4%
Road Vehicle Transport	-4%	-4%
Rail Transport	-4%	-4%
Air Transport	-5%	-5%
Water Transport	-5%	-5%
Health & medical	-4%	-4%
Communication	-4%	-4%
Trade	-5%	-5%
All other services	-4%	-4%

Table 20. Household real consumption effects

	Productivity	+Export Loss
Rural Nonag Self Employed	-3%	-3%
Rural Ag Labourers	-15%	-15%
Rural Other Labourers	-5%	-5%
Rural Ag Self Employed	-5%	-5%
Rural Other Households	-4%	-4%
Urban Self Employed	-9%	-10%
Urban Salaried Workers	-5%	-5%
Urban Casual Labourers	-4%	-5%
Urban Other Households	-6%	-6%

The second general insight from Table 20 is heterogeneity. Clearly, adverse livestock production events affect different households differently. Most importantly for the present research, it is apparent that low-income households suffer much more in relative terms. Rural Agricultural Labourers, the poorest, suffer three times as much of a decline in real consumption. This effect arises for two reasons, one on the expenditure side and one on the income side. Food prices rise because of higher marginal cost in livestock production, and they most adversely affect real consumption by the poorest households for reasons just discussed. Second, falling livestock productivity translates into lower productivity for those whose livelihoods most depend (in share of income terms) on animals and animal services, again the poorest farm households. All in all, the results for India drive home a simple message, livestock is integral to the lives and future economic opportunities of the country's poor majority, and promoting growth and value creation in smallholder livestock can be a potent catalyst for poverty reduction.

Summary of results

Clearly, more empirical work could refine the indicative results presented here, but the message of the present exercise is likely to remain the same. Livestock is an essential contributor to poor people's food security and livelihoods, especially in rural areas where the majority of global poverty persists. For this reason, sustained initiative to reduce the incidence and persistence of animal diseases is an essential component of global development policy, supporting vital capacity for the poor to advance their own circumstances.

In this study, we present two case studies of very different developing economies. Despite their differences, however, the implication of these results is clear. As long as smallholders, embedded in or in transit from subsistence, make up the majority of the rural population, and extensive poverty persists there, animal products and services will be essential to national livelihood. Moreover, those products and services support a wide array of commercial linkages between the rural poor and the rest of the economy that would be absent without the animals. Rinderpest and other bovine diseases pose a direct threat to this extensive web of economic activity, and to its capacity for facilitating market access and self-directed poverty reduction.

Endemic high-impact animal diseases like rinderpest; even if they don't induce human illness, represent major economic threats to countries with limited household and enterprise savings and other financial resources to respond effectively.

For low-income countries, a few percentage points of GDP can make the difference between meeting basic needs and large-scale human misery. Even in simple accounting terms, this amount is enough to justify large defensive investments in integrated livestock health maintenance. Although Rinderpest represents an eventual victory, our empirical results suggest that recurrent investment levels are probably too small.

Future applications

The approach outlined in this paper has provided a method to assess in a relatively rapid fashion the net benefits associated with the eradication of an animal disease. Clearly, the analysis is incomplete, and indeed in the case of rinderpest, beset by an extreme lack of data on both economic parameters (prices, trade, etc.) and costs associated with rinderpest control and eradication. Nonetheless, the methodology attempts to address the key dimensions of disease eradication as a guideline to measure future eradication impacts and as a template to organize the collection of appropriate necessary for improved monitoring and evaluation of current disease control and eradication efforts (e.g., PPR, FMD, etc.).

An important consideration in the rinderpest eradication story is that local context matters, and some aspects of control (and different levels of analysis) will be more or less important in different settings. In West Africa, the higher proportionate levels of mortality suggest a need to consider the influence on population structures on the overall cost-effectiveness of rinderpest control. The incidence of drought complicates matters, and more work will be required to tease out rinderpest impacts from other mortality effects in the livestock production system. In other cases, population dynamics will likely matter less, with the contextual aspects of the eradication programme playing an important role. India is a case in point. Between 1960-1990, mortality due to rinderpest was usually under 5 000 animals per year in a production system of well over 250 million bovines, suggesting that production impacts of rinderpest control/eradication would be marginal at best. On the other hand, the revealed impact of rinderpest eradication since 1990 has been a massive increase in market access for buffalo meat in particular, as trading partners have accepted India's rinderpest-free status. Our framework is flexible enough to tease out these nuances, providing general guidance of the scope of impacts to consider, given the local setting and data available.

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