An assessment of the *ex-post* socio-economic impacts of global rinderpest eradication: methodological issues and applications to rinderpest control programs in Chad and India

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Paper prepared for the SPIA pre-conference workshop "Innovations in impact assessment of agricultural research: Theory and practice," Foz do Iguaçu, Brazil, 18th August 2012.

WORKING DRAFT 2ND MAY 2012

I. INTRODUCTION

Animal diseases are responsible for a host of economic impacts manifesting themselves through a variety of pathways. 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 programs 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 affected 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 Africa and Asia. Major pandemics in Africa, with 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.

Other studies have highlighted the benefits and costs associated with specific control programs. The most widely cited study in this context was conducted by Tambi et al. (1999) on 10 of the 35 countries participating in the Pan-African Rinderpest Campaign (PARC). Tambi et al. (1999) weighed the costs of control 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. At a sample level, the BCR for the PARC program was estimated at 1.85, ranging from 1.06 in Cote d'Ivoire to 3.84 in Tanzania. Felton and Ellis (1978) evaluated the JP-15 program in Nigeria, highlighting the benefits from avoided mortality and impaired reproduction only; impacts on increased milk yield and growth rates were not included. Their analysis found that the net benefits to JP-15 in Nigeria yielded a BCR of

2.48, though 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. Other assessments of the socio-economic impacts of rinderpest control or the losses associated include Blakeway (1995), who computed a rather large BCR of 34 in his evaluation of the benefits of rinderpest control in South Sudan; Nawathe and Lamorde (1984) who calculated the losses from the 1983 rinderpest outbreak in Nigeria at US$2 billion; and Chuta (1990) who estimated that the late application of the rinderpest vaccine during the 1983 rinderpest epidemic reduced net revenue in the cattle sector by US$126-166 million, roughly 5 percent of the value of beef sector output.

However, most of these estimates do not include a more detailed discussion of their derivation, 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. For instance, Felton and Ellis (1978) note (but do not quantify) the potential impact of rinderpest on herd demographics in that affected herders kept 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. They also discuss the potential limits that the natural environment may exert on further expansion of livestock populations. Such dynamic and second-round considerations may have an important influence of the evaluation of animal diseases such as rinderpest.

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 impact assessment considerations in the context of animal diseases and provide 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.

II. KNOWLEDGE RESOURCES FOR ANIMAL DISEASE IMPACT ASSESSMENTS

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 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.

<< TABLE 1, FOLLOWED BY FIGURE 1>>

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. 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 labor) as a result of rinderpest eradication and control campaigns.

III. TOOLS AVAILABLE FOR ECONOMIC ASSESSMENTS OF ANIMAL DISEASES AT DIFFERENT LEVELS

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. Value chain analyses can elucidate and integrate specific livelihood impacts that other approaches fail to capture, such as the relationships within the chain among different actors that can influence behaviour and incentives for disease control. Such a framework thus moves beyond the typical 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. However, value chain studies are typically data 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 replete with disparate data that are cobbled together from available sources, making broad lessons and impacts difficult to tease out.

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. SAMs are divided into different accounts that represent a particular sector of the economy. These accounts can be relatively aggregate (e.g., agriculture) or can disaggregate different sub-sectors (e.g., maize production, beef production, etc.). 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 which 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. Roeder and Rich (2009) found that the livestock sectors of East Africa had relatively high activity multipliers (between 3-5, meaning that a $1 increase in final demand would increase economywide output by $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. However, dynamic adjustments will be a critical part of any analysis. 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 general 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.

IV. 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. We 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 combination of a micro-macro approach utilizing sector-level, SAM, and CGE analyses to obtain a fuller picture of the benefits from rinderpest eradication. In particular, 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 as follows:

- 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 1-3). To facilitate the comparison of actual events with rinderpest control with counterfactual scenarios, 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;

- 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).

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-led control efforts in Chad commenced with JP15 that began in September 1962. Vaccination coverage peaked in the first year of JP15, with over 83 percent of cattle vaccinated in 1962, and fell erratically from 1963-1970. 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 from Sudan, 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 program, 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 programs 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 programs.

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. 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. This additional mortality (computed at 0.32 percent) is added to standard mortality rates in DynMod to provide an alternative population projection in the absence of rinderpest control (see Rich, Roland-Holst, and Otte 2012 for more details). 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 historical data from the 1950s. 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. 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 killed 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 falls by 15 percent in sick animals. This figure is relatively small, but important in contexts where milk production is important (e.g., India).

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

Given the population projections from DynMod, 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 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 2000 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 Lipissier (1971) of 28.9 CFA. For the costs of the PARC and PACE programs, Oussiguere (2010) reports aggregate costs associated with both programs. As an approximation, we assumed that these funds were divided evenly in each year of the respective program. All costs were converted to 2000 constant CFA using the GDP deflator for Chad computed by the World Bank.

Table 2 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. 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.

<< TABLE 2 HERE >>

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 4. This is slightly above the BCRs of 1.06-3.84 reported in Tambi et al. (1999) that evaluated the PARC program 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 2). 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.

<< FIGURE 2 HERE >>

In figure 3, 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 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.

<< FIGURE 3 HERE >>

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). 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. Details on specific multipliers can be found in Rich, Roland-Holst, and Otte (2012). We compute that 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. 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 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 benefits, we estimated the magnitude of these linkages for the six different household groups found in the SAM (data can be found in Rich, Roland-Holst, and Otte 2012). 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 further use our SAM to conduct short-run and long-run policy simulations. For the former, we use 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).[1]

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. 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 programs in that year (750 million CFA). However, as government

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[1] 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.

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 3 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.

<< TABLE 3 HERE >>

In the latter, long-run case, we assume that livestock productivity in the counterfactual declines by 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 4 presents results for average annual changes in Chad's real macroeconomic aggregates under two scenarios designed to be indicative of chronic livestock disease like Rinderpest:

- Livestock sector productivity declines 1 percent annually from 2010 to 2030.
- Because of chronic 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 a 1 percent annual decline, as might result from the mortality and stunting associated with a chronic disease like 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.

<< TABLE 4 HERE >>

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.

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). 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

(Rich, Roland-Holst, and Otte 2012). 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 the remit of individual states (Roeder and Rich 2009). Such control efforts were successful in reducing the number of outbreaks from over 8000 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, but were not able to fully eradicate the disease. In response, the NPRE designed an intensive three-year program 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 2005 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 program 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 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 counterfactual 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 5 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 program of the 1970s and 1980s, compared to more limited programs 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 4). 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 4 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.

<< TABLE 5, FOLLOWED BY FIGURE 4 >>

When compared to a scenario of no-control, the benefit-cost ratio of the mass vaccination program becomes much higher (estimated at 5.42), with positive and large benefits relative to the additional costs (figure 5). As above, this strongly depends on the assumed mortality rate associated with rinderpest. Figure 6 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-related mortality rises.

<< FIGURE 5, FOLLOWED BY FIGURE 6>>

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 7).

<< FIGURE 7 HERE >>

To assess the rinderpest issue 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. 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 SNA 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 by 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. Multipliers from animal services are large and widely dispersed across stakeholders in the Indian economy (total activity multiplier of 4.48, household multiplier of 1.69, and total multiplier of 8.15), reflecting the importance of animal traction in the small holder agrofood supply chain and that supply chain's pervasive linkages across the Indian economy (Rich, Roland-Holst, and Otte 2012). 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 believe 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. We omit the many details here (see Rich, Roland-Holst, and Otte 2012 for the data), but a few salient aspects deserve emphasis. As would be expected, rural households gain most from livestock activities, with the poorest (labor 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. It has long been understood that market access is the primary gateway from poverty for the rural poor, and it is essential that agro-food industrialization not undermine this mechanism.

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 Tables 6 and 7. 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 more 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.

<< TABLE 6, FOLLOWED BY TABLE 7 >>

Because the India SAM was built with detailed household survey data, we can gain valuable insight about the incidence of adverse livestock events like rinderpest. Table 7 reveals two important general facts. Firstly, as was apparent in the macro results of Table 6, household real consumption falls more than household real income because the adverse price impacts are on staple commodities with limited substitution possibilities. 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 2007-8 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.

The second general insight from Table 7 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 Laborers, 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.

V. DISCUSSION

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.

Chronic animal diseases like rinderpest, even if they don't induce economywide 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.

VI. CONCLUSIONS

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 program 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 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 imapcts to consider, given the local setting and data available.

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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					
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						

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)***
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					

Table 2
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

Year	Benefits			Costs
	Baseline	High mortality	Low mortality	
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**	

Table 3
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
Agriculture (activities)	0.00	-3.55	205.18	201.63	-1.73 %
Cotton crops (activities)	0.00	0.00	27.04	27.04	0.00 %
Livestock (activities)	-0.75	-1.89	190.54	188.65	-0.99 %
Fisheries (activities)	0.00	-0.32	36.67	36.35	-0.88 %
Manufacturing (activities)	0.00	-1.66	164.69	163.03	-1.01 %
Cotton fiber manufacturing (activities)	0.00	0.00	38.21	38.21	0.00 %
Oil development (activities)	0.00	0.00	18.19	18.19	0.00 %
Construction (activities)	0.00	-0.06	57.38	57.32	-0.10 %
Informal manufacturing (activities)	0.00	-1.71	117.28	115.58	-1.46 %
Services (activities)	0.00	-5.29	532.34	527.05	-0.99 %
Government (activities)	0.00	0.59	191.07	191.66	0.31 %
Agriculture (commodities)	0.00	-4.77	275.50	270.73	-1.73 %
Cotton crops (commodities)	0.00	0.00	27.69	27.69	0.00 %
Livestock (commodities)	0.00	-1.21	202.77	201.56	-0.60 %
Fisheries (commodities)	0.00	-0.42	48.04	47.61	-0.88 %
Manufacturing (commodities)	0.00	-4.98	493.67	488.69	-1.01 %
Cotton fiber manufacturing (commodities)	0.00	0.00	39.09	39.09	0.00 %
Oil development (commodities)	0.00	0.00	18.62	18.62	0.00 %
Construction (commodities)	0.00	-0.06	58.76	58.70	-0.10 %
Informal manufacturing (commodities)	0.00	-1.75	120.15	118.40	-1.46 %
Services (commodities)	0.00	-7.04	708.52	701.49	-0.99 %
Government (commodities)	0.64	0.61	195.48	196.08	0.31 %
Land (factor accounts)	0.00	-0.92	80.08	79.16	-1.14 %
Capital, formal sector (factor accounts)	0.00	-0.38	97.29	96.92	-0.39 %
Capital, informal sector (factor	0.00	-2.04	196.43	194.39	-1.04 %

accounts)					
Labor, privileged sector (factor accounts)	0.00	-0.12	79.96	79.83	-0.16 %
Labor, non-prvileged sector (factor accounts)	0.00	-5.63	500.34	494.71	-1.12 %
Rural agricultural households (households)	-4.88	-9.27	358.99	349.72	-2.58 %
Rural public sector (households)	0.01	-0.55	70.57	70.02	-0.78 %
Urban informal sector (households)	0.00	-1.00	90.79	89.79	-1.11 %
Urban capitalist-rentier (households)	0.00	-0.64	58.27	57.63	-1.11 %
Urban public sector (households)	0.02	-0.90	113.88	112.97	-0.79 %
Urban wage workers (households)	0.01	-0.46	66.35	65.88	-0.70 %
Enterprises (households)	0.01	-2.06	241.39	239.33	-0.85 %

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

Table 4
Macroeconomic Impacts of Livestock 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%

Source: CGE model simulations using SAM of Garber (2009)

Table 5
Summary of benefit-cost ratios of differential rinderpest control scenarios in India

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

Table 6:
Macroeconomic impacts of alternative long-run livestock 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%
Ships	-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%

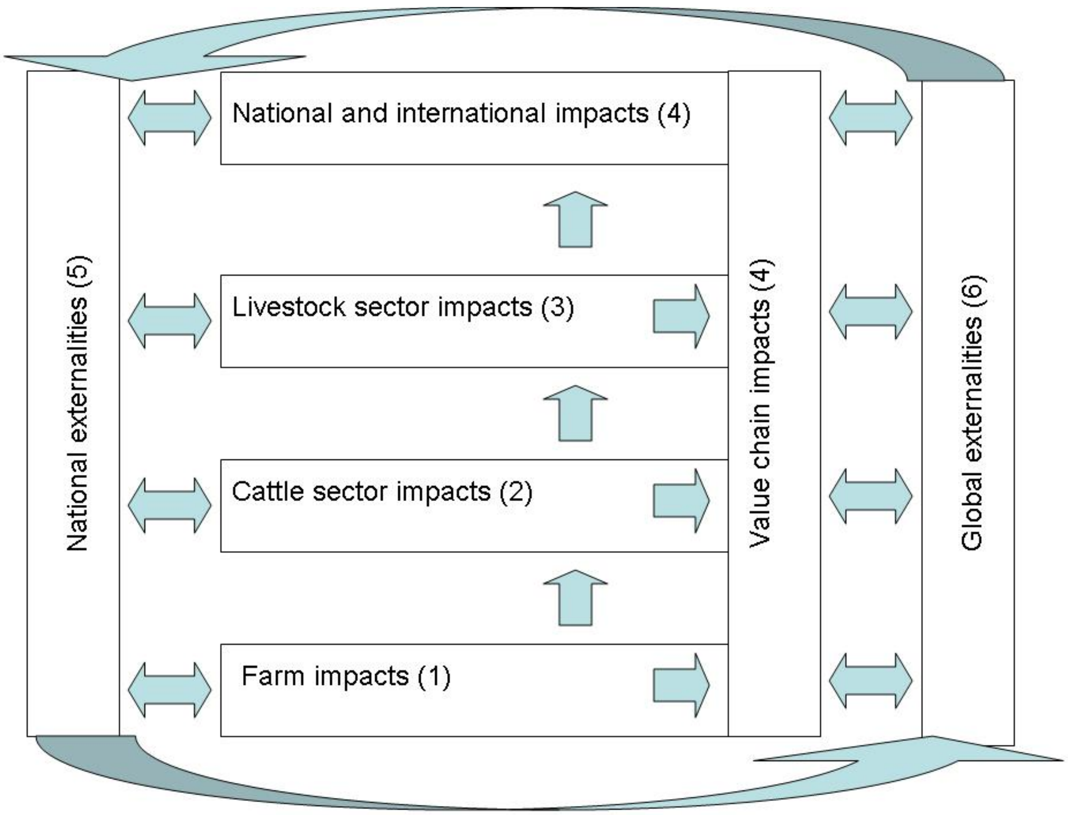
Source: Model simulations

Table 7:
Household real consumption effects from alternative livestock scenarios in India

	Productivity	+Export Loss
Rural Nonag Self Employed	-3%	-3%
Rural Ag Laborers	-15%	-15%
Rural Other Laborers	-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 Labor	-4%	-5%
Urban Other Households	-6%	-6%
Average	-8%	-8%

Source: Model simulations

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

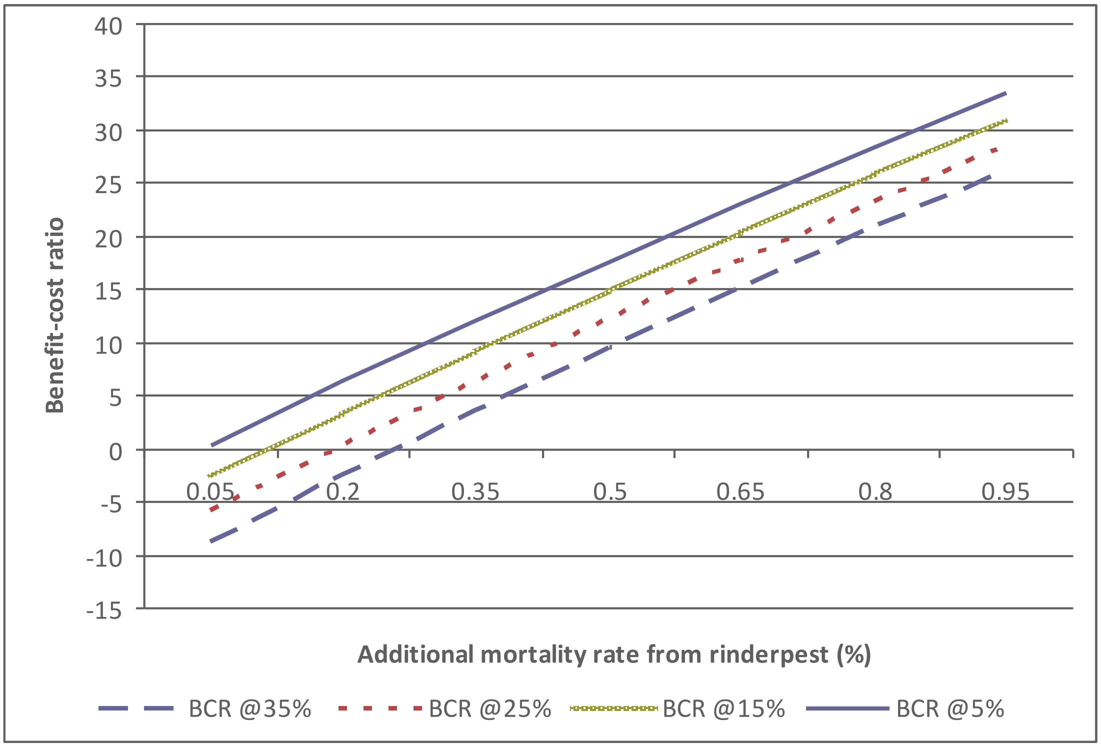


Source: Developed by the authors

Figure 2
Comparison of cattle population projections with and without rinderpest control under different scenarios, 1963-2007

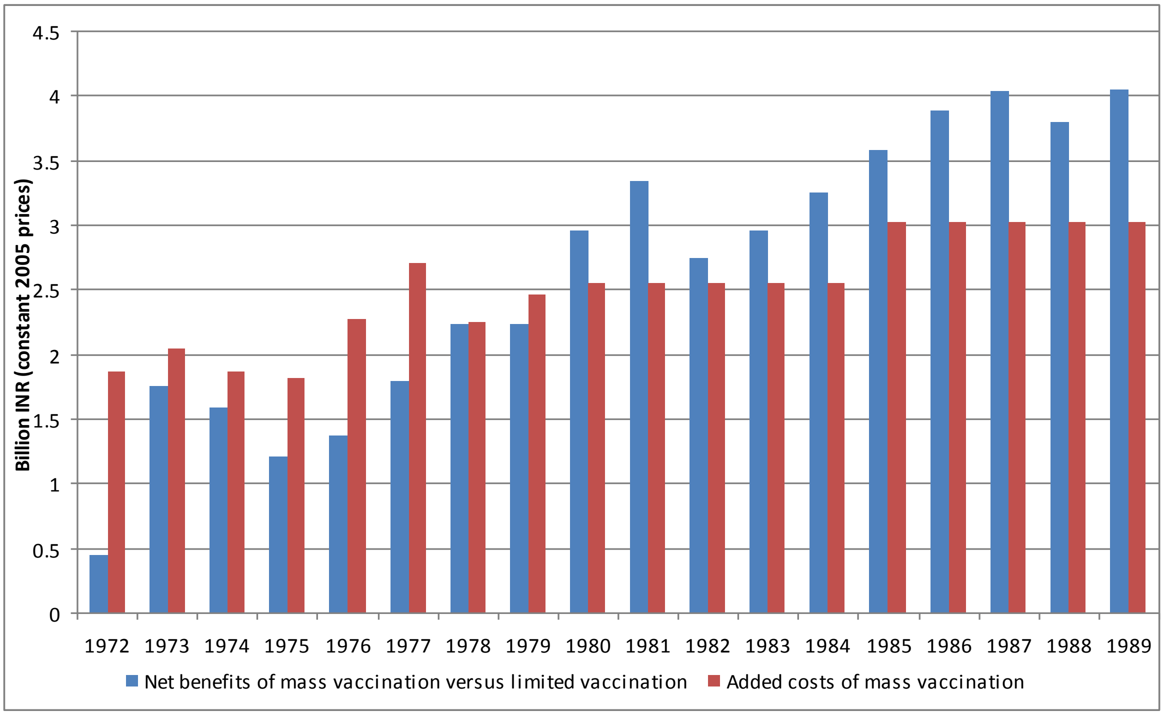
Source: Model simulations with DynMod

Figure 3
Sensitivity analysis of benefit-cost ratio eradication in Chad, based on different mortality rates and percentage of rinderpest deaths associated with drought.



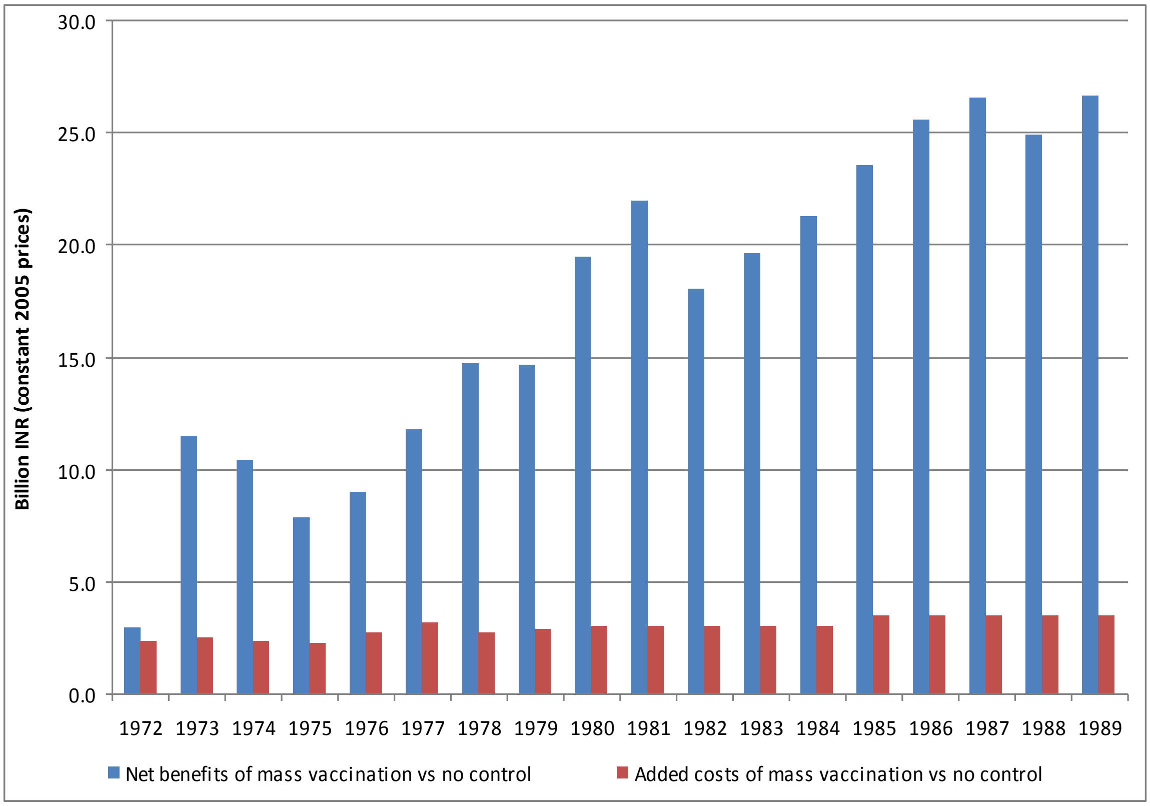
Source: Simulations conducted with DynMod

Figure 4
Added benefits and costs associated with mass vaccination versus limited vaccination in India, 1972-1989.



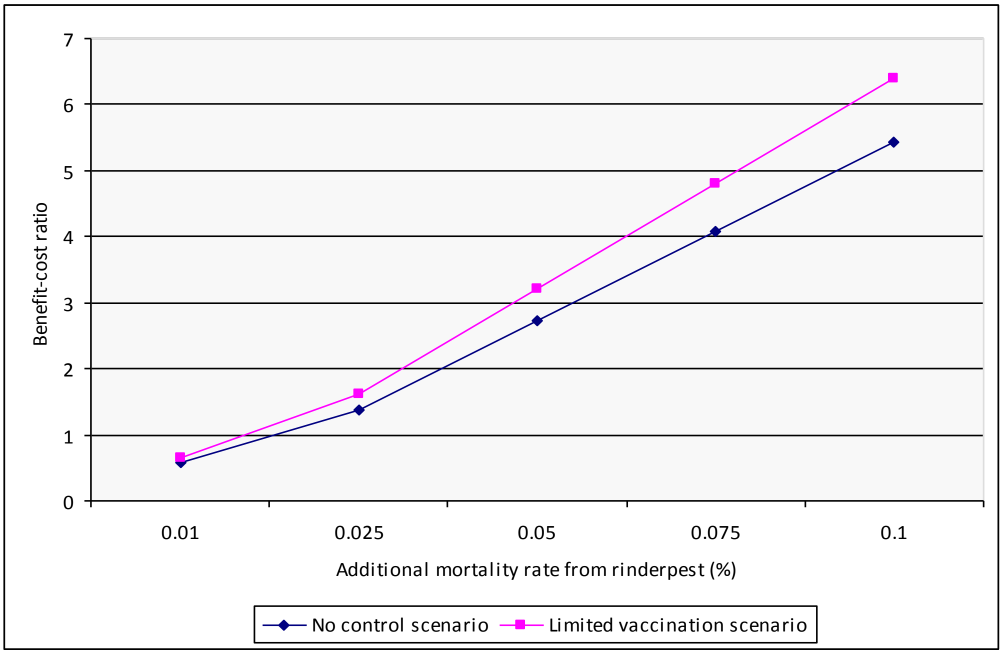
Source: Model simulations with DynMod.

Figure 5
Added benefits and costs associated with mass vaccination versus no control in India, 1972-1989.



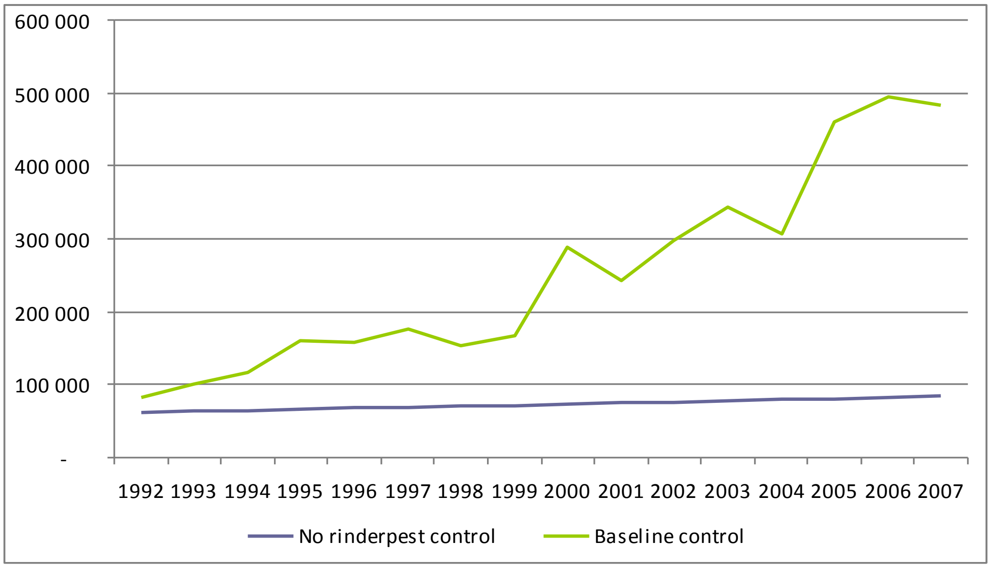
Source: Model simulations with DynMod.

Figure 6
Sensitivity analysis of benefit-cost ratio eradication in India, based on different mortality rates



Source: Model simulations with DynMod.

Figure 7
Changes in bovine meat exports associated with rinderpest control and "no control" scenario, 1992-2007.



Source: Model simulations with DynMod.