ECONOMIC IMPACT OF NEWCASTLE DISEASE CONTROL IN VILLAGE CHICKENS: A CASE STUDY IN MOZAMBIQUE

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A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Agricultural Economics

2009

ABSTRACT

ECONOMIC IMPACT OF NEWCASTLE DISEASE CONTROL IN VILLAGE CHICKEN: A CASE STUDY IN MOZAMBIQUE

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Newcastle disease (ND) is the main constraint for village chicken production in Mozambique, and chicken vaccination is the only effective way to control ND. The I-2 vaccine has been locally produced since 1999, and it is suitable for small farmers, but it is only used in some parts of the country, with very low levels of adoption. Vaccine availability is the key bottleneck for increased adoption. The current level of vaccine production is under the installed capacity, indicating potential for expansion of a vaccination program; but, it is necessary to evaluate the economic viability of the program and the feasibility of its expansion. This research evaluates the financial viability of the vaccination program at farm level, as well as the economic viability of the program in Chibuto District and all the districts the program is implemented. Also, the sensitivity of the profitability measures to ND incidence, chicken price reduction and adoption ceiling levels is evaluated. A simulation program VIPOSIM with parameters adapted to the Mozambican case is used to simulate the benefits of vaccination at farm level, while benefit-cost analysis is used to evaluate the profitability of the program. For households with flocks above 10 chickens, the vaccination is shown to be profitable, even for low levels of ND infection. Production and extension of I-2 vaccine has positive returns; and, expansion of the program to new areas should be explored and strategies put in place to speed up the adoption in areas already covered. When planning expansion of the program, areas with high incidence of ND should be prioritized.

To my parents, for their unconditional support and love.

To my siblings, for their encouragement and unending support.

To my nephew Elton, may this be an inspiration for the long way ahead in his life.

ACKNOWLEDGMENTS

I would first like to acknowledge USAID and MSU Food Security Project in Mozambique for funding my assistantship and fieldwork. I am very grateful to my major professor Dr. Cynthia Donovan, for her guidance and support throughout my master degree studies. I would like to thank my thesis supervisor Dr. Eric Crawford, for his valuable input throughout my Master’s thesis research. I am also grateful to Dr. Thomas Walker, a non-voting member of my committee, for helping me to conceptualize this study and for his insightful comments during the writing process. I would like to thank Dr. James Lloyd and Dr. Duncan Boughton for serving my committee and for providing valuable input on the thesis. Also, I thank Nicky Mason for her useful comments.

Additionally, I would like acknowledge the Animal Production Systems Group from the Department of Animal Sciences in Wageningen University, and my special thanks to Dr. Henk Udo and Dr. Theo Viets, for providing the Village Poultry Simulation Model, a tool which was extremely valuable in this research. My gratitude is extended to the Southern Africa Newcastle Disease Control Project, which was funded by the Australian Agency for International Development and implemented by GRM International, with special thanks to Dr. Robyn Alders, for providing bibliographic material. Also, I thank Dr. Joanne Meers for providing bibliographic material.

In Mozambique several institutions and individuals direct or indirectly supported my field work. My special thanks to: Manuel Josefa and other staff from CSL for providing the vaccination data set and other relevant information; Ellen Payongayong for her valuable assistance during sampling process; Dr. Harun from Veterinary Medicine

College in Eduardo Mondlane University, for sharing his extensive knowledge of ND and I-2 vaccine; a team from Animal Science Directorate in IIAM, especially Quintino Lobo and Amílcar, for sharing information on the production of I-2 vaccine in Mozambique; a team from DINAP and DNER, especially Hélder Gemo, Titos Paris and Anabela dos Muchangos, for providing relevant information on chicken vaccination in Mozambique; VETAID, World Vision, SPP and Chibuto District Agricultural Services, for the sharing information on chicken vaccination; Mr. Jorge Francisco from IIAM for editing the map; teams from CESE, DFDTT and Mozambique MSU FSIII, for their logistic support; the drivers, Mr. Reginaldo, João Dunduro and Mr. Manhiça for their safe driving. Also, I'm very grateful to chicken farmers in Chibuto, for their cooperation and generosity.

The words might not be enough to thank my friends and fellow graduate students in Michigan, especially Mukwiti, Wezi, Nicky, Kirimi, Tina, Martin, Kay, Alexandra, Ramzi, Anna, Sean and Alex. With all we shared together, my time in USA was not only about academic learning but also about school of life. I would also like to thank Tammy Brown and her family, for the time we shared, their friendship and hospitality. Your support in every way made it clear that I have family in Michigan. Lastly, but definitely not the least, I am very thankful to God for the strength, wisdom, inspiration, courage, and many other uncountable blessings, which are proof his unfailing love.

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LIST OF ACRONYMS

ACIAR – Australian Center for International Agricultural Research

AIDS – Acquired Immunodeficiency Syndrome

DINAP – National Livestock Directorate

DNER – National Extension Services Directorate

FAO – Food and Agriculture Organization

HIV – Human Immunodeficiency Virus

IIAM – Institute of Agricultural Research of Mozambique

IRR – Internal Rate of Return

MAE – Ministry of State Administration

MADER – Ministry of Agriculture and Rural Development (currently called MINAG)

MINAG – Ministry of Agriculture

MTN – Meticais, Mozambican currency.

ND – Newcastle Disease

NGO – Non-Governmental Agency

NPV – Net Present Value

PARPA – Government’s Strategic Plan to Reduce Poverty

SANDCP – Southern Africa Newcastle Disease Control Program

SSA – Sub-Saharan Africa

TIA –*Trabalho de Inquérito Agrícola* (National Agricultural Survey)

VIPOSIM – Village Poultry Simulation Model

CHAPTER I: INTRODUCTION

1.1. General Background

The Mozambican agricultural sector plays a very important role in the socio-economic development of the country. Most of the population in Mozambique lives in rural areas and they depend directly or indirectly on agricultural activities for their livelihoods. The agricultural sector is dominated by smallholders who farm in a risky environment that is vulnerable to droughts and floods (World Bank, 2006).

Although the incidence of rural poverty decreased from 69 percent in 1996-97 to 54 percent in 2002-03 (Government of Mozambique 2006), rural poverty remains widespread. Rural inequality appears to have increased moderately from 1996 to 2003, as rural growth benefited upper income quintiles relatively more than low-income quintiles. The poorest households, particularly female-headed households, were significantly disadvantaged during this period of growth (World Bank 2006). According to Boughton et al. (2006), rural household incomes remain very low, and they are critically low for the poorest 60 percent of the population. Food security is a concern for rural households given Mozambique’s vulnerability to weather and market induced risks (World Bank 2006). Absolute poverty is still a major challenge to the Mozambican government and according to the government’s Strategic Plan to Reduce Poverty (known as PARPA), the government seeks to reduce absolute poverty to 45 percent by 2009 (Government of Mozambique 2006). The agricultural sector is seen as a critical component in the PARPA. By promoting sustained agricultural production and productivity growth, the government can help to ensure growth of the rural sector, improving livelihoods and reducing risk and vulnerability of households who depend on agriculture for their livelihoods. Development programs benefiting the poorest among the rural farmers constitute the key for effective poverty eradication, and programs targeting these farmers should be given special attention.

Livestock production constitutes an important component of the agricultural economy of developing countries. The livestock sector makes significant contributions to the livelihood of smallholders and the rural poor. Livestock serves to increase farm income, while it also diversifies farm income, thereby reducing risk and vulnerability, especially in regions where potential for crop production is limited (World Bank 2006; Branckaert and Guèye 1999). The contribution of livestock goes beyond direct food production and includes multipurpose products and uses, such as skins, feathers, fiber, manure for fertilizer and fuel, power and transportation. Animals also provide a means of capital accumulation and serve as barter products in societies where there is limited circulation of currency (Branckaert and Guèye 1999). Furthermore, livestock holding is associated with status in a community and other cultural and religious traditions (Branckaert and Guèye 1999).

Chickens are the most significant livestock species in terms of level of ownership, access to animal protein, and the potential for earning cash income in Southern Africa (SANDCP 2005). Rather than caged, large-scale poultry production, Mozambican smallholders have “village poultry” systems that are generally owned and managed by rural poor people, usually women. Village chickens are most often kept under a free-range, low input management system (SANDCP 2005). In Sub-Saharan Africa (SSA) about 85 percent of all households keep poultry, with women owning 70 percent of them (Guèye, 1998). In Mozambique, the national agricultural survey data (TIA 2002; TIA

2003; TIA 2005) indicate that more than 65 percent of rural households keep chickens. In their analysis of the determinants of rural income in Mozambique, Walker et al. (2004) found that possession of some chickens results in marked superiority in rural income: households with 30 or more chickens have 33 percent higher agricultural income. Furthermore, Walker et al. (2006) show that chickens are among the first 10 agricultural commodities with the highest contributions to total value of production, and that a 20 percent increase in chicken production could result in a four percent reduction in the severity of poverty. Thus, productivity enhancements for village poultry have a significant bearing on the economic well being of a large portion of Mozambican rural households. Increased poultry production can also result in improved nutritional wellbeing, whether the chickens and eggs are consumed in the household or sold to generate income. Village chicken production is a reliable and viable tool for eradication of rural poverty and food insecurity in Mozambique.

Newcastle disease (ND) is the most serious constraint for village chicken production throughout the world, particularly in developing countries (Branckaert and Guèye 1999). ND is the most pathogenic of the annual poultry epidemics in Mozambique, and it is the main cause of mortality of chickens accounting for between 50 and 100 percent of deaths annually in rural households (Bangnol 2001; MADER 2004; MADER 2005). According to TIA data, about 66 percent of households who raised chickens during the 2005-2006 cropping season reported losing birds because of disease. The high prevalence of ND in Mozambique and its resulting losses suggest that improvement of household poultry production requires capacity to ensure sustainable ND control.

Given the nutritional, cultural, and economic importance of village chickens and the severity of the ND problem, several vaccines for ND control have been tested and used in Mozambique. However, the level of chicken vaccination against ND is still very low. According to National Agricultural Survey data (TIA 2006) in 2006, only six percent of households who raise chickens, vaccinated their chickens against ND.

Sustainable ND control requires maintenance of high levels of quality control in production, distribution and administration of the vaccine, all in a timely and low cost manner. Village chicken production systems are based on minimum input use with low productivity. Any cost-effective strategy without high capital costs that increases their productivity will assist in poverty alleviation and food security improvement (Alders and Spradbrow 2001). Thus, investments in production and extension of technologies for ND control may have significant returns and, more importantly, may have a relevant role in the reduction of rural poverty and food insecurity.

There are both direct and indirect beneficiaries of ND control. The indirect benefits may result from reduced village chicken mortality which increases poultry and possibly egg supply for the market and/or household consumption. Given that village chickens are one of the main assets owned by the poor households, adoption of ND control by these families may have a significant effect on poverty reduction. Thus, ND control has a vital role in increasing poultry production, contributing to the improvement of household food security and poor rural income.

1.2. Problem Statement

Currently two vaccines are used by small-scale farmers for ND control. The first is the I-2 vaccine, a thermo stable live vaccine which was developed and tested locally with technical and financial support from the Australian Centre for International Agricultural Research (ACIAR) ND Control Project. The second vaccine is called Itanew, an inactivated ND vaccine imported through a livestock project funded by the African Development Bank (Alders et al. 2000). Between the two vaccines, I-2 is more suitable for small-scale Mozambican farmers due to its lower costs (World Bank 2006; Alders and Spradbrow 2001). In addition, I-2 does not require technical skills for its application, and it stimulates all forms of immunity (Alders and Spradbrow 2001). Therefore, the I-2 vaccine has better prospects for enhancement of village poultry productivity in Mozambique.

Even though the I-2 vaccine has been produced by the Institute of Agricultural Research of Mozambique (IIAM) for use in village chickens since 1999, until now it has been used only in selected districts in the provinces of Gaza, Inhambane, Tete, Nampula and Zambezia. Program administrators working with the I-2 vaccine decided to launch the program in these provinces with prospects of later expansion to other districts and provinces. Selection of these provinces was based on staffing levels for both the Directorate of Rural Extension Services (DNER) and the National Directorate of Livestock (DINAP)[1], provincial levels of poultry production, and existence of Non-governmental Organizations (NGOs) and private companies interested in participating in

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[1] DINAP, is the entity which coordinates and implements livestock disease control programs in the Ministry of Agriculture (MINAG), in collaboration with DNER. For more details about the decision making and management of I-2 vaccine in Mozambique, see section 3.4.

the program [2]. Availability of the vaccine constitutes the main constraint for adoption, and IIAM production levels of the vaccine are based on requests from DINAP. Currently about 2,500,000 doses are produced per vaccination campaign[3]. Given that three vaccination campaigns are carried out per year, the actual level of production is far below the installed capacity which is 23,000,000 doses per year, about three times the current levels of production. This suggests that there is a potential to expand the vaccination program to the other provinces.

However, decisions on coverage require additional information on the economic viability of the vaccination program and on the likelihood that the program will be expanded successfully and sustainably in the long term. Expansion of the ND control program to other sites implies the need for considerably higher budgets (vaccines production inputs, transportation, and refrigeration equipment), and will compete with other development interventions for scarce resources. As demand for scarce funds grows, better evidence is needed to show that investments in the program can generate attractive returns (Batz et al. 2003), or at least meet some of the main economic, political and social objectives. Scientists, research administrators and policymakers face increasing pressure to justify continued public investment in agricultural research and development programs (Alston et al. 1998). Socio-economic impact studies of investments can help policymakers to assess the value of past investments and to prioritize alternative future investments. Evaluation studies of past, current and proposed development programs are very important for effective and efficient use of available resources. Empirical evidence of the economic impact of investment in the ND control program using the I-2 vaccine in

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[2] Hélder Gemo, conversation with author, Maputo, 18 August 2007.
[3] Quitino Lobo, internet conversation with author, 20 February 2009

already implemented zones is fundamental for proper formulation of policy and strategies of expansion of the program of ND control using this vaccine.

Despite the relevance of this kind of study for the researchers and policy makers, few studies of evaluation of the ND control program have been conducted in Mozambique. Woolcock et al. (2004) studied the impact of ND vaccination on household welfare in Mozambique using a static poultry model. Although the parameters they used in their model to represent "without-control" situation were based on the literature and portrayed a typical African village chicken flock, the parameters for "with-control" situation were purely based on assumptions; no specific data were used to get the parameters of the benefits of vaccination. Furthermore, researchers have given little attention to the evaluation of efficiency of investments in production and extension of the I-2 vaccine at aggregate levels.

This study fills the gap of the study of Woolcock et al. (2004) by using farmers' surveys and elicitation methodology in combination with parameters derived from empirical literature to estimate the benefits of ND control at the farm level. In addition, this study will provide information on return of investments on ND control at the regional level. The findings of this study will provide information about the profitability of ND control to farmers and to society in general. This information will be helpful in providing insights relevant for expansion of ND disease control using the I-2 vaccine to the other provinces and for prioritization of development activities which compete for scarce funds.

1.3. Research Questions

The study addresses the following questions:

i. Is it financially viable for farmers in Chibuto District to invest in the vaccine I-2 to protect their chickens against ND?

ii. How sensitive are the farm-level annual net benefits of the vaccination to various hypothetical disease mortality scenarios and possible chicken price reductions?

iii. Are the investments of the government and NGO agencies to promote the I-2 vaccine in the District of Chibuto economically viable?

iv. Are the investments of the government and NGO agencies to promote the I-2 vaccine in the five provinces where it is currently used economically viable?

v. Is it economically viable to expand the production and use of the I-2 vaccine in Mozambique?

vi. How sensitive are the aggregate profitability measures to changes in mortality rates, chicken prices, and adoption ceiling levels?

1.4. Hypotheses

This study tests the hypothesis that investments in the program of vaccination of village chickens against ND have positive returns at the farm level as well as at the district and national levels. This hypothesis will be verified if: i) the net benefits associated with the use of the vaccine at the farm level are positive and generate a sufficiently high marginal rate of return to warrant adoption; and ii) the net present value (NPV) is positive or the economic rate of return of the investments in the vaccine production and distribution at the aggregate level is greater than the opportunity cost of capital at the aggregate level.

A Village Poultry Simulation Model (VIPOSIM) with parameters adapted to the Mozambican context is used for determination of annual incremental benefits resulting from chicken vaccination at the farm level. Data on village poultry production systems collected in Chibuto district are used for simulation. In both deterministic and stochastic analyses, the distribution of flock size in Chibuto is used in defining different categories of initial flock size that are considered for determination of overall annual incremental benefits at the farm level. In stochastic analyses, @Risk software is used in combination with VIPOSIM to measure the profitability of the vaccination, and the without-control ND mortality rate is treated as a random variable. For aggregate analyses, the results of incremental annual benefits at farm level are used, and the costs involved are incorporated in the analysis for determination of aggregate measures of profitability.

In deterministic analysis for both farm and aggregate levels, sensitivity of profitability measures to without-control ND mortality rates and chicken price reductions is evaluated. Also, for aggregate analysis, the sensitivity of the NPV to the assumptions of adoption ceiling level is evaluated.

1.5. Organization of Thesis

This thesis is divided into five chapters. Chapter 2 gives an overview of the Mozambican poultry production sector and information about the epidemiology of ND. Then, the system of production and distribution of the I-2 vaccine in Mozambique is described and their constraints discussed. In Chapter 3, the literature on impact assessment is briefly reviewed; the theoretical framework for analysis of animal diseases and their control is presented, and methodologies of analysis as well as the data sources are discussed. Then, procedures for the analyses are described in detail. In Chapter 4, the results of the analyses are presented and discussed. Chapter 6 summarizes the main findings and their policy implications, and then further research is recommended.

CHAPTER II: AN OVERVIEW OF VILLAGE CHICKEN PRODUCTION

2.1. The Relevance of Poultry Production

Village chickens are the most significant livestock species in terms of level of ownership, access to animal protein, and the potential for earning cash income (SANDCP 2005). In SSA, 85 percent of all households keep poultry, with women owning 70 percent of them (Guèye, 1998). Poultry provides approximately 20 percent of protein consumed in developing countries (Jensen and Dolberg 2002). According to TIA data, poultry is the most popular livestock kept by small and medium scale farmers in Mozambique (see Table 1).

Table 1: Percentage of Rural Households Owning Livestock in Mozambique

	Year		
Livestock Species	**2002**	**2005**	**2006**
Chickens	74	65	70
Goats	37	38	34
Cattle	14	19	17
Pigs	19	19	15
Ducks	19	13	13
sheep	3	4	3
Turkey	1	1	1

Data Source: National Agricultural Survey (TIA)

Village poultry play a vital role in the improvement of nutritional status and income of many poor rural households and are a global asset for many millions who live below the poverty line (Copland and Alders 2005). Village poultry provide scarce animal protein in the form of meat and eggs and provide the owners with a form of savings which can help in times of need to meet essential family expenses such as medicines, clothing and school fees. Families can also increase their income by taking advantage of seasonal peaks in poultry demand, such as at religious festivals or celebrations (Johnston and Cumming

1991). The benefits of family poultry production include other functions for which it is difficult to assign any monetary value. These include pest control, provision of manure and household contribution to traditional ceremonies and festivals. In addition, village chickens provide some benefits in terms of cleanliness and hygiene (Johnston and Cumming 1991). According to the results of household survey in Chibuto, small-scale farmers raise chickens for three primary reasons: regular consumption within the household, serving guests (social obligations), and sales in emergency situations (Table 2).

Table 2: Reasons for Raising Chickens among Households in Chibuto District

Reason	% of households
Regular Consumption	83
To Serve Guests	69
Sale in Emergency Situations	48
Regular Sale	32
Cultural Ceremonies	21
Consumption in Holidays	13
Exchange for Other Kinds of Food	11
Other	<1

Data Source: Chibuto Survey in 2007
Note: Each household could had up to 8 reasons during the interview

Furthermore, village chickens play an important role in households where there is a lack of able-bodied workers due to war or HIV/AIDS, and in households that have a disabled or elderly member (Copland and Alders 2005). According to the same authors, in households headed by widows, children or grandparents, chickens represent the easiest species to raise for sale and home consumption, providing a source of high quality protein and vitamins that play an important role in the nutrition of HIV/AIDS patients.

2.2. Poultry Production System in Mozambique

Poultry production in Mozambique is carried out in two systems of production: the free-range poultry system in rural and peri-urban areas and the caged poultry system which is based on commercially improved poultry farms concentrated in urban or peri-urban areas. The free range system dominates with scavenging chickens as an integral part of the farming system. According to the Chibuto District survey, essentially all (99.6 percent) of the households interviewed let their chickens scavenge. In general, the management system of village chickens involves minimum input use, requiring the lowest capital investment of any livestock species with a short production cycle (Copland and Alders 2005) and waste from household consumption is occasionally used to supplement the diet. Only seven percent of interviewed households stated that they sometimes buy supplements for their chickens.

In addition, most farmers in the village poultry sector in Mozambique do not provide housing for their chickens. About 26 percent of interviewed households only provide housing to their chickens during the night and less than one percent of households provide housing continuously. Although housing is usually suggested as a means to improve chicken productivity, it appears to be controversial for several reasons. First, in discussion groups in Chibuto, farmers revealed little interest in housing their chickens because of the perceived high risk associated with housing. According to the farmers when housing chickens, rather than keeping them free and sleeping in trees, there is high risk of losing all the chickens at once either due to attack of predators where they are confined or due to theft. Also, when chickens are confined, they are no longer able to scavenge around for their own food, and the farmer will need to invest in supplements.

This can be a big problem for poor farmers who most of the time do not have enough resources even to meet their own food needs.

The village chicken production system is also characterized by low output levels, which are mainly because of high mortality due to diseases and predation. ND is found to be the most serious constraint for village chicken production in Mozambique; it is the main cause of mortality of chickens (Bangnol 2001; MADER 2004; MADER 2005). ND is endemic in Mozambique, occurring every year in the rural poultry sector (MADER 1992). According to the survey in Chibuto district, 87 percent of interviewed households reported that they had lost chickens due to disease in the two previous years. ND is particularly devastating for small village farmers who usually have limited means of protecting their flocks. It is commonly recognized that little progress could be made in the village poultry industry unless ND is controlled.

2.3. Epidemiology of Newcastle Disease and Its Control

ND is a highly infectious viral disease caused by a paramyxovirus which mainly affects poultry (Alders and Spradbrow 2001). The ND virus can infect through the respiratory tract, the ocular mucous membranes and the digestive tract. The incubation period usually ranges from 2 to 15 days depending on the strain of virus. Under village conditions, the virus is unlikely to survive outside the host for more than a month.

The virulence of the disease depends on the particular strain of the virus. Of the highly virulent strains, which are particularly common in South-East Asia and Africa, some grow in the gut (viscerotropic strains), while others grow mainly in the central nervous system (neurotropic strains). The most common indication of a serious outbreak of a neurotropic strain of the disease is seen in a nervous symptom exhibited in infected birds where the neck twists right back and the chickens simply fall over and die (Alders and Spradbrow 2001). Less virulent strains, such as those that are endemic in Australia, affect only the respiratory system, with varying degrees of severity. Symptoms may include loss of appetite, a dramatic drop in egg production, increased respiration, and coughing, gasping and even rapid death without any exhibition of other symptoms. Most avian species, domestic or feral, can be infected by strains of ND virus; however, the consequences of these infections will vary with the strain of virus and the species of the host infected (Spradbrow, 1999). Chickens are the most susceptible host (Alders and Spradbrow 2001). Ducks and geese are also susceptible to infection, but these species rarely succumb to the disease.

ND is highly transmissible: birds are normally infected through direct contact with diseased or carrier birds, but the virus can also be carried on contaminated objects such as chicken or egg crates, feed, vehicles, dust and clothing. The virus is usually inactivated by direct sunlight, but in cool weather the virus can survive in feces and contaminated housing for up to 21 days. The virus can also persist in poultry products (meat and eggs) and can be carried by migrating wild birds. Human activity was found to influence the occurrence of ND. Seasonal high sales of chickens and population movements are some of the factors that lead to outbreaks.

Eradication of ND is unlikely and there are few poultry species which are resistant to the disease. Continual vaccination programs currently offer the only effective way of controlling ND (Udo et al. 2006; Alders and Spradbrow 2001). Thus, chicken vaccination is one of the most important technical possibilities to improve village chicken production.

ND control was found to have positive effects on bird off-take, egg production, egg off-take and flock size (Udo et al. 2006; Woolcock et al. 2004). Of the households surveyed in Chibuto who participated in a vaccination program, 80 percent perceived improvements in their chicken production resulting from ND control.

Different types of vaccine were developed for ND control. Conventional vaccines used in formal vaccination adopted in commercial chicken enterprises are inappropriate for village chickens for several reasons. First, village chickens are raised in small, multi-age and free-range flocks; therefore it requires more effort and time to vaccinate them using conventional vaccines than when the I-2 vaccine is used. Second, commercial vaccines are heat-labile, requiring complex cold-chains to link the vaccine producers and users, which is difficult to maintain under village conditions. Finally, the cost of purchase is higher than the I-2 vaccine because they can only be purchased in relatively higher number of doses (Alders and Spradbrow 2001). However, new vaccines, including the I-2, are thermo stable, such that they can withstand limited periods without refrigeration prior to use. The I-2 vaccine was developed by ACIAR and it is free of commercial ownership such that seed cultures of I-2 are made available without cost to countries that wish to test or produce their own vaccine (Alders and Spradbrow 2001). I-2 is highly suitable for village chickens, is very cheap, and does not require a continuous cold chain. It is safe for both chickens and handlers (i.e., overdosing causes no ill effect) and protection can spread horizontally from vaccinated to non-vaccinated birds. Furthermore, it does not require technical skills for its application. I-2 has proven to be effective in trials under laboratory conditions and in villages. According to the results of field trials in

Mozambique, vaccination of chickens with I-2 vaccine via eye drops in the areas affected by virulent ND virus increases their survival rate to about 80 percent (Dias et al. 2001).

2.4. System of Production and Extension of I-2 Vaccine in Mozambique

Currently I-2 vaccine is used in 44 districts within 5 provinces: Gaza, Inhambane, Tete, Nampula, and Zambézia. The process of production and extension of I-2 vaccine in Mozambique involves a series of stakeholders. DNER, IIAM, DINAP and SANDCP are involved in vaccine production, distribution, vaccinator training and monitoring of the program at the national level. IIAM is responsible for production of the I-2 vaccine as well as for monitoring and evaluation of performance of the vaccine itself. DINAP is responsible for delivery of requested amounts of the vaccine to the Provincial Livestock Services (SPP). DINAP also coordinates monitoring and evaluating the vaccination program at national level. DNER is responsible for vaccinator training and vaccine extension evaluation. SANDCP provided the vaccine seed, and also provided some technical and financial support to the production and distribution of the vaccine during the initial stage of the program.

SPP is responsible for providing cold chains for the vaccines, and for delivery of the vaccine in the districts. SPP collects vaccine sales revenues from the districts and delivers the funds to DINAP. In addition, SPP is responsible for providing information on vaccine requirements and vaccination data to DINAP. SSP participates in monitoring and evaluation of the vaccination program at provincial level.

The Services of Agriculture in the District coordinate the vaccination programs at district level. They are responsible for delivery of the vaccine to the vaccinators and participating

NGOs. In addition, they are responsible for collecting vaccine sale revenues from the vaccinators or NGOs to deliver to SPP, and participate in monitoring and evaluation of vaccination program at district level.

NGOs provide technical and financial support for vaccinator training and vaccine distribution in some villages. In addition, they monitor and evaluate the vaccination program in the villages they cover. The main NGOs participating in the ND control programs in Mozambique are World Vision, Heifer International, ADRA, and VETAID. A private company for mineral extraction, CSL, has a very active role in providing technical and financial support for chicken vaccination and vaccine conservation in Chibuto. This company participates in vaccination to fulfill some of the requirements of the government, where private companies have to contribute directly in some development activities in the communities where they operate.

The vaccinators are community members trained in ND and vaccination issues, so that they can vaccinate chickens in their villages. The vaccinators are not paid any salary; they earn the margin they get after paying the cost of vaccine doses. The bottles contain about 250 doses: given that each dose is 0.50 MTN, if the vaccinator is able to use efficiently all doses in the bottle, he/she gets a margin of 100 MTN after paying the cost of the bottle which is 25 MTN. Thus, the profits the vaccinator gets depend on his/her vaccination performance. Also, as a result of participating in the program, vaccinators usually tend to be the biggest chickens raisers in the communities.

2.4.1. Analysis of Critical Issues Relevant for Improvement of Production and Extension of I-2 Vaccine in Mozambique

The limited coverage of vaccine distribution systems seems to be the bottleneck for diffusion of the vaccine in Mozambique. According to Gemo et al. (2005), there are limited resources to expand public extension in Mozambique, and some hard choices must be made in terms of the size of the public extension system and the role of NGOs and the private sector in delivering extension. Partnership with NGOs and other private entities in delivering the vaccine to the final users is a good strategy to overcome public funding limitations. However, relying only on that strategy may pose some threats in terms of sustainability of vaccine access by the farmers in the long term. For the particular case of Chibuto, the vaccination program is consistently well functioning only in areas covered by CSL; in the other areas the access to this program is negligible. If for some reason CSL stops its actions in the area of vaccination, there will definitely be problems in controlling ND in that district. This suggests that there is a need to look for additional strategies in order to ensure sustainability of the extension of the vaccine in the long term.

I-2 vaccine can be produced in wet or freeze dried forms. Although both forms of I-2 are thermostable, they can only withstand limited periods without refrigeration prior to use. They still require cold storage and cold transport to maintain their maximum viability. However, the freeze dried form lasts longer out of cold storage while the wet form requires a more reliable distribution system. This suggests that among both forms of I-2 vaccine, the freeze dried form is more suitable for the Mozambican context. Nevertheless, the I-2 is currently produced only as a wet vaccine in Mozambique because the freeze dryer is not operational. The amount of vaccine produced by IIAM is based on the request from DINAP; they do not produce more than the requested amount to avoid spoilage[4]. As a result, their level of operation is below production capacity.

This suggests that purchase of a new freeze dryer or repairing the old one could be a means of increasing the efficiency of production and of distribution systems. By restarting production of dried vaccine, production levels will no longer be limited to short term requests from DINAP because the dried vaccine can last longer; it will be possible to produce and to transport larger quantities of the vaccine to the provinces at once. Production of larger quantities will allow for exploration of economies of scale, reducing the production costs per unit of vaccine. Also, for districts with a reliable cold storage system, an amount of vaccine to cover more than one vaccination campaign would be sent at once, reducing the unit cost of transportation. But, there will still be a need to assess whether the resulting cost reduction will compensate the additional costs of storage that will be incurred when keeping the vaccine longer in the provinces.

On the other hand, production of higher amounts of vaccine with a longer lifetime may allow IIAM to explore prospective markets such as the commercial poultry sector and other countries in the region, with the possibility of increasing its levels of production in order to meet the efficient capacity. But, for that to happen, first the vaccine needs to be commercially registered.

Making the vaccine available does not seem to be a sufficient condition for guaranteeing positive and sustainable results. For example, the data set on chicken vaccinations and number of chickens provided by CSL shows that in communities vaccinated by one

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[4] Quitino Lobo, internet conversation with author, 20 February 2009

vaccinator, Eduardo Mondlane, the flock size increases are outstanding and consistent over the time (see Table A1 on the Appendices). Personal communication with this vaccinator and the leader of those communities suggested that involvement of the leader in the campaign and the fact that he always talked about the importance of vaccination in all the community meetings was the key to the success of vaccination in this area, such that vaccination in those communities is currently driven by the demand from the farmers. On the other hand, visits and groups discussion in another community in which the leader did not promote the vaccine revealed the opposite in terms of success of vaccination, even though the vaccine was made available there. The lack of interest in vaccination shown by the leader of that community supports the idea that involvement of community leaders is a crucial aspect in influencing ND control and ensuring sustainability of the program. Thus, community leaders and district administrators can be useful resources to speed up the adoption of the vaccine in the district when they address the problem of ND and the importance of vaccination in public community meetings.

Vaccination of chickens in the community is a seasonal job for the vaccinators, since it is just carried out for a total of three months during a year (a month in each of three campaigns). In the remaining months, vaccinators do not have anything to do related to the ND program. Limited seasonal employment may constitute a problem for sustainability of the vaccination program because the vaccinators can easily sacrifice the vaccination program in favor of better prospects for any given season. This programmatic vulnerability mainly applies to male vaccinators who have high propensity of migrating to other places seeking jobs. Making vaccination a full-time job in the form of other related local employment opportunities in periods outside the vaccination campaigns could enhance the performance and sustainability of the program by lessening the chance that the vaccinators commit themselves to other engagements when needed for the vaccination campaign. While the actual application of the vaccine does not require technical skills, the campaigns require organizational skills and vaccinators become more efficient in time, such that constant retraining would lower the efficiency of the program.

CHAPTER III: LITERATURE REVIEW AND METHODS

3.1. Overview of Impact Assessment Studies

A large number of impact assessment studies have been undertaken in the agricultural sector in the developing world. Most of them are focused on the evaluation of programs related to development and extension of improved crop varieties (Bellon et al. 2005; Marasas et al. 2004; McSween et al. 2006). Impact assessment of animal health interventions has captured the attention of agricultural socio-economists (Pritchett et al. 2005; Johnston and Cumming 1991; Otte and Chilonda 2000; Bennett 2003; McDermott et al. 2001).

The majority of impact assessment studies evaluate, in financial or economic terms, the efficiency of development and/or extension of technologies using profitability measures. In the financial valuation, the benefits and costs are valued in terms of market prices unadjusted for distortions; in the economic valuation, prices are adjusted to reflect the economic values of inputs and outputs.

In addition to understanding the economic efficiency of the allocation of the resources in development programs, researchers also want to assess the impacts of these programs on poverty, food security, equity and the environment, among other aspects (McDermott et al. 2001). Given a wide range of development objectives, some development programs may be accepted when they are not economically efficient because they benefit vulnerable or target groups, or meet specific policy objectives. Even though the other components of evaluations are important, this study only addresses the economic efficiency component of impact evaluation. Incorporating other components of evaluation would require additional work, beyond the scope of the current research.

According to Joshi (2003), efficiency analyses of development programs can be undertaken at three levels according to the phase of implementation of the program, namely, ex ante, ex post and concurrent assessments. The ex ante assessment is typically used to quantify the returns of proposed projects and prioritize the investment agenda; it is usually done to justify funding for different investment options (Alston et al. 1998; Joshi 2003). The ex post assessment approach is used to determine the impact of past investments, and it is usually undertaken when the research outputs and technologies are largely adopted (Joshi 2003). The concurrent evaluation is the intermediary level and it is done to identify the impediments for larger adoption of the technology. Its purpose is to correct the gaps and provide feedback and fine-tuning of the technology according to stakeholders' requirements (Joshi 2003). Given that the producers have started adopting the I-2 vaccine, but the levels of adoption are still very low, this study falls under concurrent analysis.

Many economic approaches are used to quantify the economic effects of investments in development programs. Quantitative techniques are divided into three broad groups: 1) econometric; 2) programming; and 3) economic surplus (Masters et al. 1996; Alston et al. 1998; Maredia et al. 2000). The choice of the methods depends on data availability, the objectives of the research and/or the nature of the problem (including the economic level involved and the complexity of the problem), the timing of the study and the availability of resources such as time, money and analytical tools (Alston et al. 1998; Otte and Chilonda 2000). Furthermore, Pritchett et al. (2005) argue that in the field of animal disease the choice of the analytical approach for impact assessment is influenced by the focus of the impact analysis (production level, market prices, welfare), level of analysis (geographically, marketing phase), and proposed policy alternatives.

The econometric approaches aim to estimate marginal productivity of investments during a long period of time for a variety of research activities (Masters et al. 1996). They are based on functional forms such as production, profit, and supply functions to estimate a change in productivity due to investment (Maredia et al. 2000). In these approaches, investment is treated as a variable, allowing for the calculation of the marginal rate of return on investment (Alston et al. 1998). In general, econometric approaches assess the change in marginal productivity at the macro level. The programming approach tries to identify one or more optimal technologies or research activities from a set of options given the constraints. This approach is based in the constrained optimization problem.

Economic surplus approaches include consumer-producer surplus, benefit-cost, and total factor productivity. Total factor productivity is the ratio of the total value of the product and the value of the whole set of inputs, and it shows the residual left after incorporating the contribution of inputs (Joshi 2003). Total factor productivity can be decomposed into the contribution of research resource allocation and other determinants.

The consumer-producer surplus framework is the most widely used means of ex ante evaluation of the impacts of agricultural research in a partial equilibrium framework (Alston et al. 1998). This approach estimates aggregate returns on investment in a particular project by measuring the change in consumer and producer surplus from a shift of supply curve due to the adoption of the technology. In this approach, it is assumed implicitly that adopters of the new technology have higher productivity relative to non-adopters. This approach can also be used in an ex post evaluation framework; in this case, the changes can be measured using elicitation methods or econometric analysis (Alwang and Siegel 2003). In economic surplus methods, the stream of benefits is compared to the stream of costs, and indicators of the return of the investments such as benefit-cost ratio, net present value (NPV), internal rate of returns (IRR) and payback period are used for assessment.

This approach has an advantage of requiring less information than the other methods. The information on how much the technical change shifted the supply curve and the elasticities of supply and demand for the commodity, are the only empirical information required. In addition, it is a relatively simple and flexible approach that can be applied to the broadest range of situations (Masters et al. 1996). It can be modified to account for the effect of trade and price policy on the distribution of benefits between consumers and producers. However, the consumer-producer surplus methods do not provide clear cut evidence about the impact of a program on measures of aggregate poverty (Alwang and Siegel 2003).

The benefit-cost method of analysis is a variant of the consumer-producer surplus method. In this method, the economic surplus changes may not be explicitly measured, but economic surplus calculations are implicitly incorporated when IRR, NPV or benefit-cost ratios are calculated to place a value on the extra output or the inputs saved (cost reduction) because of the technology use (Alston et al. 1998). According to the same authors, the advantage of employing benefit-cost methods is that the values of demand and supply elasticities are simply imposed on the analysis by assumption, eliminating the need to obtain elasticity estimations. For the valuation of extra output due to a technology use, a single market price is used and it is assumed that the supply curve is vertical and shifts against a horizontal demand curve. For valuation of inputs saved (cost reduction) at current level of production, a horizontal supply curve which shift down against a vertical demand curve is considered (Alston et al. 1998). However, the implicit economic surplus calculations ignore all regional and international prices effects due to technology use, as well as any distributional effects (Alston et al. 1998). In this study the benefit-cost method is used for the analysis. In addition, sensitivity analysis of prices is performed in order to evaluate how much the prices of chickens can decrease without affecting the overall profitability of the program.

3.2. Economics of Animal Disease

Disease represents a negative input in the process of converting resources or production factors into products, goods and services available to people; it causes direct economic losses for the producer and a potential loss of value in the view of the consumer (Otte and Chilonda 2000). According to Bennett (2003), disease in livestock has seven main economic impacts, namely: i) reduction in the level of marketable outputs; ii) reduction in (perceived or actual) output quality; iii) waste (or higher level of use) of inputs; iv) resource costs associated with disease prevention and control; v) human health costs associated with disease or disease control; vi) negative animal welfare associated with disease; and vii) international trade restrictions due to disease and its control. In addition, FAO (2001) considers animal diseases an example of invasive species, and categorizes six areas of their impact, namely, production effects, markets and price effects, trade effects, impact on food security and nutrition, human health and the environment, and financial costs.

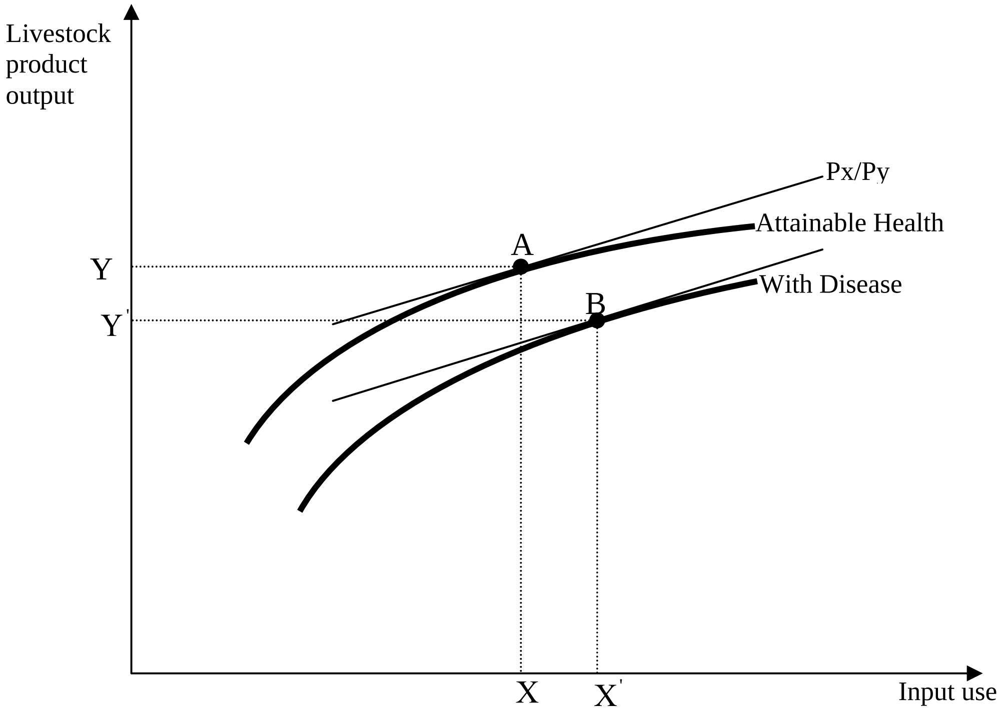

Figure 1: The Effect of Disease on Livestock Production (Source: Bennett 2003)

In the production area, the presence of the disease results in an inefficient production process, that is, livestock producers operate on a lower production function than in the situation of absence of disease. Figure 1 shows the physical effect of disease on livestock production (inefficiencies in production process) in terms of both output losses and input use. In the presence of disease, instead of operating at point A on the “attainable health” production function with output level Y and input use of X, producers operate at new equilibrium point B, on the disease production function with lower output level Y' and/or higher input use X', given output and input prices, P_Y and P_X, respectively. This suggests that producers readjust to the changed relationship between inputs and outputs caused by the disease, achieving a new equilibrium. The effect of animal diseases in a given production system is a reduction of the efficiency with which inputs/resources are converted into outputs/products, decreasing productivity (Otte and Chilonda 2000).

Furthermore, Otte and Chilonda (2000) classify the effects of the disease as direct and indirect effects. The direct losses may occur when: (i) disease destroys the basic resource of the livestock production process (mortality of breeding or productive animals); (ii) disease lowers the efficiency of the production process and the productivity of resources employed (e.g. reduced feed conversion), and (iii) disease may reduce the quantity and/or quality of output. The indirect losses include: (i) losses through additional costs incurred to avoid or reduce the incidence of the disease; (ii) detriment of human health well-being; (iii) sub-optimal exploitation of otherwise available resources through forced adoption of production methods which do not allow the full exploitation of the available resources and/or through revenue foregone as a result of denied access to better markets. According to Bennett (2003), the presence or absence of disease may have an effect, not only on production, but also on both output and input prices. For example, if the majority of producers adhere to the programs of disease control, the output supplied in the market increases, and as a result, the price of the product in the market may decrease. According to Pritchett et al. (2005) disease impacts are generally easy to identify but may be difficult to quantify.

3.3. Theoretical Framework for Impact Assessment of ND Control

The measurement of economic benefits of agricultural technology consists of comparing the benefits in the situation with a particular technology to a counterfactual that represents what would have occurred without the technology, known as the “with” and "without" situations. The difference is the incremental net benefits due to investment in the technology (Gittinger 1982; Alston et al. 1998). For this particular study, the "with situation" is represented by a situation where the I-2 vaccine is used for ND control and, in the "without situation", no vaccine is used. The effective control of ND increases the efficiency of resource use in the affected population, through avoidance of chicken mortality due to ND, and consequently shifts the supply curve for chicken outputs to the right. The ND vaccine can be considered a productivity-enhancing technology, and as a result of its use, the consumer and producer surpluses change (Figure 2).

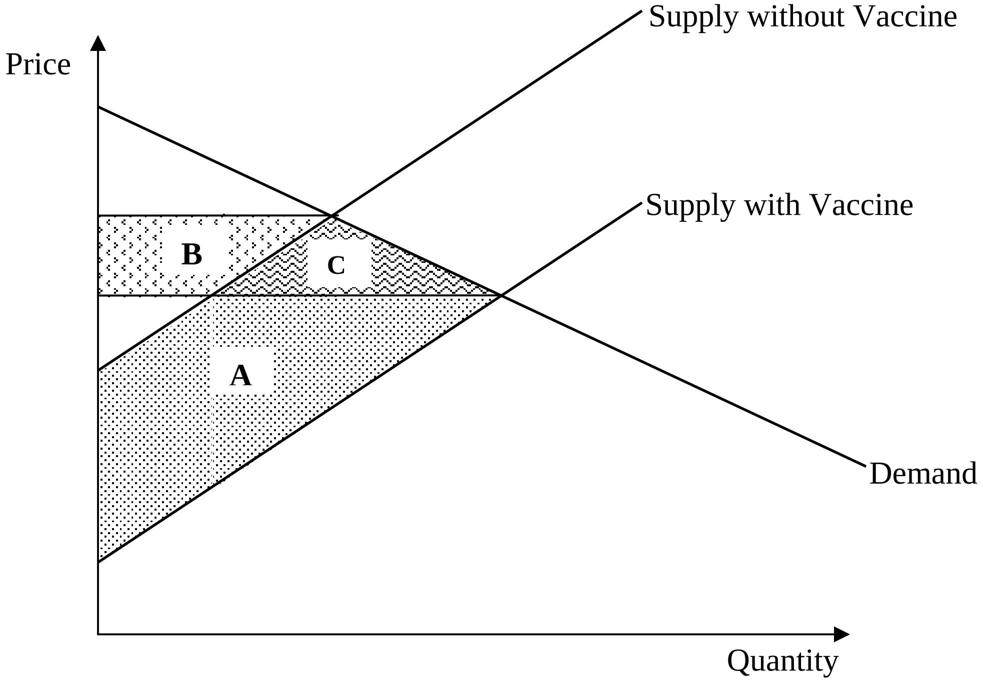

Figure 2: Impact of Vaccine Use in Village Chicken Production (Adapted from Masters et al. 1996)

As illustrated in Figure 2, for producers, the impact of vaccine use is to avoid the losses due to the disease, reducing production cost. The benefits to the producers are represented by area A. However, vaccine use may also reduce the price received by producers due to the increase in quantity supplied. This reduction in price reduces producer surplus by area B. The net gain of producers is area A minus area B. Producers net gain is positive only when the demand is relatively more elastic than the supply. In a situation where demand is relatively inelastic compared to supply, only a limited quantity of the good is wanted and the producers lose from technical change. The consumers always benefit from technical change: they gain what is lost by the producers due to price reduction (area B in figure 2), plus the economic surplus of the increased quantity (area C) (Masters et al. 1996). For the society as a whole, the impact of vaccine use is basically the gains of areas A and C. The area B is just a transfer from the producers to the consumers. Given that small scale producers of village chickens are also the main consumers, this study only focuses on total social gains.

The net social gains of investments in a technology depend not only on the elasticities of demand and supply, but also on the productivity increase generated by the technology, the equilibrium price of the product, the adoption rate, the costs of research and implementation of the program, and the timeframe between research and adoption. According to Bennett (2003), three basic types of information are required to quantify the benefits of disease control: (i) the disease incidence; (ii) the magnitude, incidence and distribution of disease effects, and (iii) the treatment and/or prevention measures undertaken.

3.4 Description of Study Area

The primary data collection was carried out in Chibuto, a district located in the Southern region of Mozambique, in Gaza Province (see Figure 3). It has an area of about 5,653 Km^2 and an estimated population of 203,910 in 2005. Climatically, the district is characterized by a low level of rainfall ranging from 400 to 600 mm per year in the coastal area; For the interior area, the level of rainfall is even lower (MAE 2005). In general, the seasonal rainfall trend follows unimodal patterns with high rainfall levels observed between November and March; however, the rainy season is quite irregular in terms of starting time, length, levels and distribution. The Limpopo River has an extremely important role in the performance of the agricultural sector in this district; it is used for irrigation, enabling agriculture in large areas which would be unsuitable otherwise.

The estimated poverty incidence in the district was about 60% of households in 2003 (MAE 2005). Agriculture is the basic economic activity in the district and it is dominated by small-scale farmers who occupy about 52,000 ha (9 percent of total cultivated area). The average cropping area per household is about 1 ha. The main subsistence crops are maize, rice, cowpea, cassava and vegetables, which are generally produced in an intercropped system using local varieties and traditional tools. Large-scale private sector holdings occupy a significant portion of the most productive land and employ about 15 percent of labor in the district. In some areas, animal traction is used in agricultural production activities. The main cash crops are sugar-cane, cotton, tobacco, and cashew. Cashew is a very important cash crop in the district; Chibuto is the second biggest supplier of raw cashew to the cashew processing industry in the province. About 25,000 people keep small ruminants and swine. More than 40,000 people keep poultry, and most of them are kept under a free-range scavenging system. Non-farm activities such as wood and coal extraction and fishing also contribute greatly to the income of thousands of households in the district (MAE 2005).

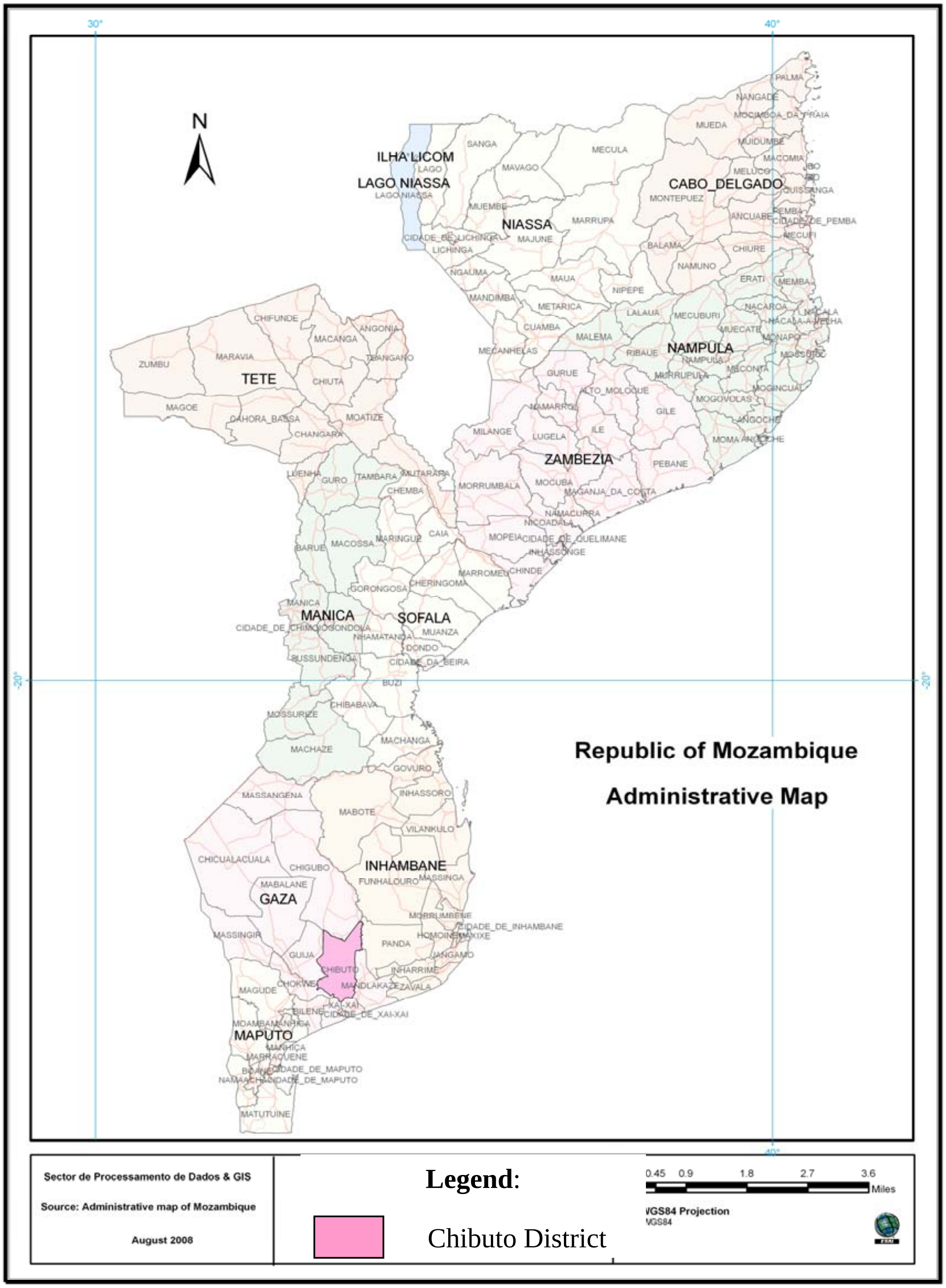

Figure 3: Location of the Study Area (Source: Administrative Map of Mozambique)

3.5. Description of Data and Methods of Collection

A formal household level survey was conducted in July of 2007. The stratified sampling technique was employed to select 226 households who raised village chickens in four villages. In the group of interviewed households, 127 are participants and 95 are non-participants in the vaccination program. One of the villages covered by the survey did not implement a chicken vaccination program at all. The non-participant households were selected randomly within the village, based on the list provided by the local leaders. Participant households were selected based on a vaccination data set provided by Corridor Sands Limited (CSL) Company, which is one of the partners in the implementation of the ND prevention program in Chibuto district. This survey collected household information on demographics, assets, chicken production systems, marketing, constraints faced in chicken production in the district, cost of the vaccine, and farmers' perceptions of the usefulness of the vaccine. This information is valuable for evaluation of the ND control program.

Additional data was collected in August of 2008. Semi-structured group interviews of the village poultry producers in the four previously visited villages were conducted. The objective of these interviews was to gather relevant information on village chicken life cycle, growth trajectory, off-take, likelihood of ND occurrence in the region, and dynamics of flock size versus management and disease incidence. This information was useful in modeling the village poultry production system and in determining the benefits of ND control at the farm level.

TIA data sets provide additional information for farm level analyses as well as aggregate analyses, including estimation of adoption rates and estimation of the levels of poultry off-take[5]. Census data are also used to estimate the benefits at aggregated levels. Furthermore, estimates of costs involved in production and transfer of the vaccine are based on information provided by IIAM, MINAG, SANDCP, CSL and NGOs involved in the ND control program. These costs involve the production of the vaccine (salaries, infrastructure, equipment, and administrative costs) and the costs of extension programs required to distribute the vaccine and to speed up adoption.

3.6. Measurement of Impacts of ND Control in Village Poultry: VIPOSIM

Village poultry production systems are complex, thus their studies require insight in the dynamics of the production system (Asgedom 2007; Udo et al. 2006). According to the same authors, temporal variation in village poultry is a result of interaction of several factors, including flock mortality, egg production, reproduction, bird off-take and egg off-take. In addition, the dynamics of village poultry are influenced by random phenomena. Thus, measurement of the impacts of interventions in this complex and dynamic system requires research tools that integrate the different processes and management options involved. Simulation models are one type of research tool that can be used to model the impacts of interventions in poultry production systems, especially if probabilistic effects can be incorporated in the analysis (Asgedom 2007).

VIPOSIM (**VI**llage **PO**ultry **SI**mulation **M**odel) is a dynamic simulation model used by Asgedom (2007) to assess the impacts of different management strategies in a poultry production system. VIPOSIM was developed by a team from Wageningen University in the Netherlands, and it was validated with data from Tigray, Ethiopia.

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[5] Consumption and sales

Conceptualization of VIPOSIM includes six processes related to production and utilization of chickens: flock mortality, flock off-take, egg production, egg loss, egg off-take and reproduction (incubation and hatching). VIPOSIM performs calculations in time steps which represent reproduction cycles, i.e., a time needed by a broody hen to produce and hatch eggs, and then to rear chicks. Each step has a length of a season of 3 months and the maximum number of steps in the model is 12, which corresponds to a period of 3 years (Asgedom 2007). VIPOSIM was programmed in Microsoft Excel® and integrates quantitative relationships of various elements of the system in a series of mathematical equations. (For more details about mathematical procedures of conceptualization of VIPOSIM see Appendix A 1.).

In the VIPOSIM model, a flock is categorized in five categories of chickens according to age and gender: i) the chicks group includes all chickens with age less than or equal to three months; ii) cockerels are male chickens with age superior to three months but not yet adult; iii) pullets are female chickens older than three months but not yet adult; iv) hens are female adult chickens; and v) cocks are male adult chickens. According to the farmers in Chibuto district, chickens are adult at the age of six months. There is a variation of some of the input parameters across chicken categories. These variables include the flock size, mortality rate due to disease, mortality due to predation, and bird off-takes.

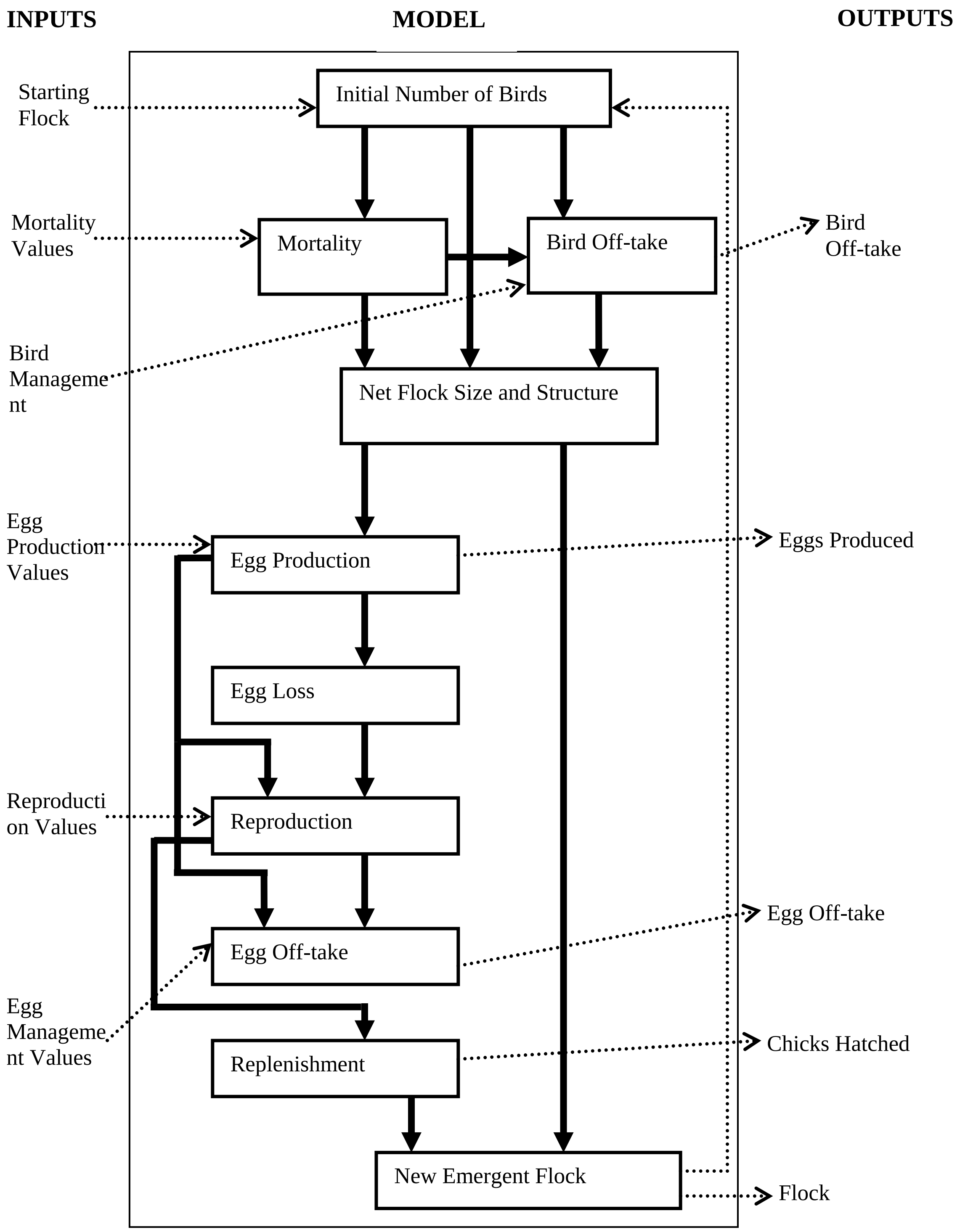

Figure 4: **Schematic Representation of Sequences of Events in the VIPOSIM for a Reproduction Season** (adapted from Asgedom 2007).

Figure 4 illustrates the sequence of the events in VIPOSIM; the broken arrows represent inputs and outputs variables of the model. The chicken production and utilization parameters are introduced in VIPOSIM as input variables. Those variables include initial size and composition of flock, mortality rates, bird sales and consumption rates, egg production, reproduction parameters (incubation and hatching), egg sales, egg loss, egg consumption rates, and bird off-take limits. The inputs variables are believed to be related to agro ecology and husbandry conditions, and they differ across the seasons.

Economic input parameters such as prices of birds and eggs and costs of production are also introduced into model. The prices of birds and eggs used in this study are based on TIA data. VIPOSIM categorizes cost input parameters into costs of labor and costs of intervention. As the output, the VIPOSIM model gives the numbers and values of bird off-take and egg off-take, and the final composition of the flock for each season during the three-year period of simulation.

This simulation model has an advantage of allowing for incorporation of random phenomena by using random numbers as coefficients of standard deviations in the simulations. It can be transformed easily into a deterministic model by setting all the standard deviations to zero. However, the model is very restrictive because it assumes that all the random parameters follow a normal distribution, which may not be true.

3.7. Adaptation of VIPOSIM to the Context of the Study

Given the limitations of VIPOSIM, the objective of the research, and data availability, various changes were made in order to accommodate the model to the current context of the study. Many changes were based on knowledge of Mozambican village chicken production systems for village chicken.

In this study, chicken production and utilization parameters are developed from the household survey and farmer group discussions in Chibuto as well as from the National TIA data. These parameters are then used as the inputs of the adapted VIPOSIM model. The VIPOSIM model requires information on production and utilization, some of which is not available for Mozambique. In the case of insufficient information, original parameters developed for the VIPOSIM model are used, based on the assumption that production and utilization parameters are similar for village chickens in Mozambique or elsewhere. For example, during the process of data collection in Mozambique, categories of chickens were not taken into account for the parameters of flock size, mortality and bird off-takes. Thus, the parameters needed for each category were generated based on general information collected and the relationship between the parameters across the categories in the default input data of VIPOSIM. These data were used by Asgedom (2007) to validate the model.

In the design of VIPOSIM, the input parameters of mortality are categorized in three groups: mortality due to the disease, mortality due to predation, and mortality due to other reasons. However, due to the nature of the data collected and objectives of the analysis in this study, only two categories of mortality parameters are defined: mortality due to ND or mortality due to other reasons (combining predation and other causes). For the third category designed in the model values of zero are entered.

In addition, VIPOSIM categorizes the input parameters for rates of bird and eggs off-take into two groups: sales and home consumption. In the adapted VIPOSIM, bird off-take input parameters are treated as one broad category of off-take, and TIA 02, TIA 03, TIA 05 and TIA 06 are used to compute the off-take rates. It is assumed that there is no off-take for chicks. Also, only consumed eggs are considered; the sale of eggs in Chibuto is negligible.

Since in the village poultry production system there is very low use of production inputs, only the cost of vaccination is included in the simulations as an additional cost of chicken vaccination; it is assumed that the additional costs of labor or other inputs resulting from chicken vaccination is negligible.

Similar to the original model, it is assumed that during a year, some input parameters vary across the seasons. Their variation is based on Mozambican farmers' perceptions of the best and worst periods and the range of values they provided. In Chibuto, farmers reported occurrence of ND over the last two quarters of the year, thus inputs of mortality due to ND are only incorporated for the third and forth quarters in the adapted VIPOSIM. For the other quarters zero values are entered.

Also, farmers reported seasonality in the losses due to predations and other causes. According to them, in the hungry season (wet season, from October to February) there is a lack of feed, and chickens tend to go far from the houses scavenging for food, making them more vulnerable to predators than in the dry season. In addition, because of food scarcity there is higher occurrence of theft. Moreover, the relatively denser vegetation in the villages during the wet season harbors predators. Thus, the last quarter of the year has the highest rates of bird losses due to predations and other causes, while the second quarter of the year has the lowest rates. The other two quarters have intermediary values (Table 3).

Table 3: Rates of Mortality Due to Predation and Other Causes

	Predation & Other Losses in Chibuto					
Season	**Chicks**	**Pullets**	**Cockerels**	**Hens**	**Cocks**	**Average**
1	42.3%	5.1%	3.1%	11.2%	1.5%	**20.5%**
2	32.5%	7.2%	9.0%	6.4%	0.4%	**16.0%**
3	39.2%	11.1%	6.3%	4.5%	2.4%	**18.4%**
4	49.2%	7.8%	1.7%	6.0%	6.6%	**22.1%**

Data Source: Group Discussion in Chibuto in 2008

Because it is believed that the dynamics of poultry systems will differ for “with-control” and “without-control” situations, these two situations are simulated separately. However, to capture only the impact of ND control for a given scenario[6] of analysis, the input parameters entered are the same for both situations, except for the level of ND mortality and the cost of the ND control.

VIPOSIM was designed to generate both direct benefits (bird and egg off-take) and indirect benefits (manure and the value of having birds in case of urgent cash or social needs). However, in this study, only direct benefits resulting from avoidance of bird loss are considered for the analyses.

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[6] Different scenarios are defined in the study based on the ND mortality rates

The initial flock size is expected to have a positive effect on the size of the benefits of vaccination obtained at farm level; the bigger the initial flock size, the larger is the number of chickens expected to be saved by vaccination, and consequently, the higher are the expected benefits of vaccination. Thus, for determination of overall benefits of ND control at farm level in the situation where initial flock size is not treated as random variable, there is a need to ensure that the initial flock size incorporated as an input in VIPOSIM is a representative flock size. In the event of asymmetric distribution of initial flock size, different categories of initial flock sizes are created. For a given scenario and situation (with or without-control), a separate simulation was performed for each of the initial flock size categories to get the benefits for each category. Then, the overall benefit of ND control of that scenario is given by the sum of the benefits of each category weighted by the respective frequency. This is one of the key modifications in the adapted VIPOSIM. The identification of flock size categories and their use is discussed in depth in section 3.8.

In the stochastic simulations, to overcome the restriction imposed by the assumption of normal distribution of the parameters in the stochastic simulations of VIPOSIM, @Risk component is incorporated. VIPOSIM is set to deterministic mode, and @Risk software is used to generate the distribution of the results based on the best fit probability distribution to data of the variables treated as random variables (in this study the random variable is ND mortality rates).

3.8. Analysis of the Impact of Chickens Vaccination

To assess the impact of vaccination, indicators of economic efficiency, such as Net Present Value (NPV) and Internal Rate of Return (IRR), are estimated. These indicators can be estimated in different levels of aggregation (farm level, district level and national level), and data on costs and benefits in each level are required. In addition, an appropriate discount rate is required for the analyses. However, in this study, the profitability measures (IRR and NPV) are only generated for aggregated levels of analysis where the time value of money becomes important because the aggregate analysis covers a long period of time and investments may change over the time. For the household level analysis, since the value of investments in the vaccine is very low and the costs do not change substantially from year to year, the results are presented in terms of annual net benefits associated with vaccination[7]. The net benefits are given by the difference in the off-take values (bird and eggs) from VIPOSIM results with and without ND control and vaccination costs.

Investments in production and diffusion of ND control technology generate benefits when the technology is adopted by farmers. The benefits of I-2 vaccine use could be in terms of an increase in the quality of chickens produced, increased flock size and/or increased off-take. Regardless of the type of benefits, their amount at the aggregate level depends on the level of adoption of the technology. Thus, estimation of the levels of adoption of the technology is one of the prerequisites for benefit-cost analyses.

Due to the low level of quality differentiation in the market for village chickens in Mozambique, and to difficulties in getting quality improvement data on village chickens resulting from vaccination, in this particular study, only benefits related to increased off-take of chickens and eggs are considered. There are additional benefits not addressed here

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[7] The results at farm level are presented in terms of annualized total present value of the net benefits over the 12 seasons of simulation

(manure, social roles of chickens, etc.) that may increase due to vaccination, but they are not considered in the study in part because it is difficult to assign a monetary value to these benefits.

3.8.1. Measurement of Annual Net Benefits of ND control at Farm Level

The annual net benefits of using ND control technology in a household depend on the size of the initial flock, the likelihood of being affected by ND, the mortality rates due to ND, and the rate of vaccination against ND in that particular year. In the model, at the household level, the rate of vaccination is given by the ratio between the numbers of chickens vaccinated and the size of the flock in each vaccination campaign.

Estimation of the rate of vaccination at household level is complicated because it requires very detailed information on the flock size and numbers of chickens vaccinated in each campaign during the year, and such data are hard to obtain. Rural households in Mozambique are likely to vaccinate less than 100 percent of their flocks because, among other reasons, it is difficult to catch all the chickens due to the feral nature of village chickens. According to the results of the survey in Chibuto, about 20 percent of the interviewed households who participated in the ND control program did not vaccinate 100 percent of their flocks in their last vaccination. Not being able to catch all the chickens on vaccination day was the main reason, stated by 90 percent of the households, for incomplete vaccination. Nevertheless, estimation of the rate of vaccination at household level may not be a big concern when a large proportion of the flock is vaccinated because of the nature of the I-2 vaccine. I-2 is a live vaccine and according to Alders and Spradbrow (2001) and M. Harum (personal communication, August 20, 2007), the virus can be transmitted from vaccinated to non-vaccinated chickens in close contact, protecting all the flock, including non-vaccinated chickens. Furthermore, vaccinating village chicken flocks at 3-4 month intervals also provides protection for newly hatched chicks (Alders and Spradbrow 2001). Thus, to simplify the analysis, in the "with technology" scenario it is assumed that all birds were vaccinated, i.e. the rate of vaccination at household level is 100 percent.

Adapted VIPOSIM simulations[8] are performed for the village poultry production system in order to estimate the benefits of vaccination at farm level. The benefits of chicken vaccination at farm level are determined by applying partial budgeting procedures to the results of simulations. For each scenario considered in the analyses, two simulations are performed: one of them represents the "without technology situation" in which the without-control ND mortality levels are incorporated, and the other simulation represents the "with technology situation", where vaccination costs are incorporated, and ND mortality rates are reduced to with-control levels. In the "with technology situation", the mortality due to ND is reduced by 80 percent (20% of "without-control" ND mortality levels). The reduced mortality levels are based on the findings in field trials in Mozambique (Dias et al. 2001), which demonstrated that in the field, vaccination reduces but does not eliminate mortality due to ND in flocks vaccinated.

Because in the presence of ND there might be a dramatic drop in number of egg laid per clutch, an increase in egg production is another component that should be considered in modeling the benefits of ND control, by introducing higher reproduction parameters in the "with-control" situation than in the "without-control" situation. However, there is no information on how much egg produced per clutch increases as a result of ND control.

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[8] This refers to simulations performed with modifications described in section 3.7.

Furthermore, protection of non-vaccinated chickens by horizontal transmission from vaccinated chickens is a potential positive externality related to chickens vaccination, but this is also not included in VIPOSIM due to lack of information.

Both stochastic and deterministic simulations are considered in the analysis. In the deterministic analysis, all the standard deviations in VIPOSIM are set to zero; while in stochastic analysis for this research, ND mortality rates are treated as a random variable, VIPOSIM is set to deterministic mode, and @Risk software is used to generate a distribution of the net benefits based on the best fit probability distribution of data collected on ND mortality rates.

3.8.1.1. Considerations of the Effect of the Flock size on the Benefits

For a given overall level of mortality due to ND in a region, the mortality rates are expected to vary across the flock sizes. For households with bigger flock sizes, the mortality level is expected to be relatively higher than in households with smaller flock sizes. The reason for this expectation is that ND is transmitted through physical contact between chickens, and the bigger is the flock size, the higher is the contact between chickens, and the higher are the chances of infecting each other.

Therefore, based on the distribution of the size of flock in the data collected in Chibuto district (see Figure 5), in simulations of a given overall level of mortality due to ND in the community, different levels of mortality are used across the different flock sizes (see Table 4).

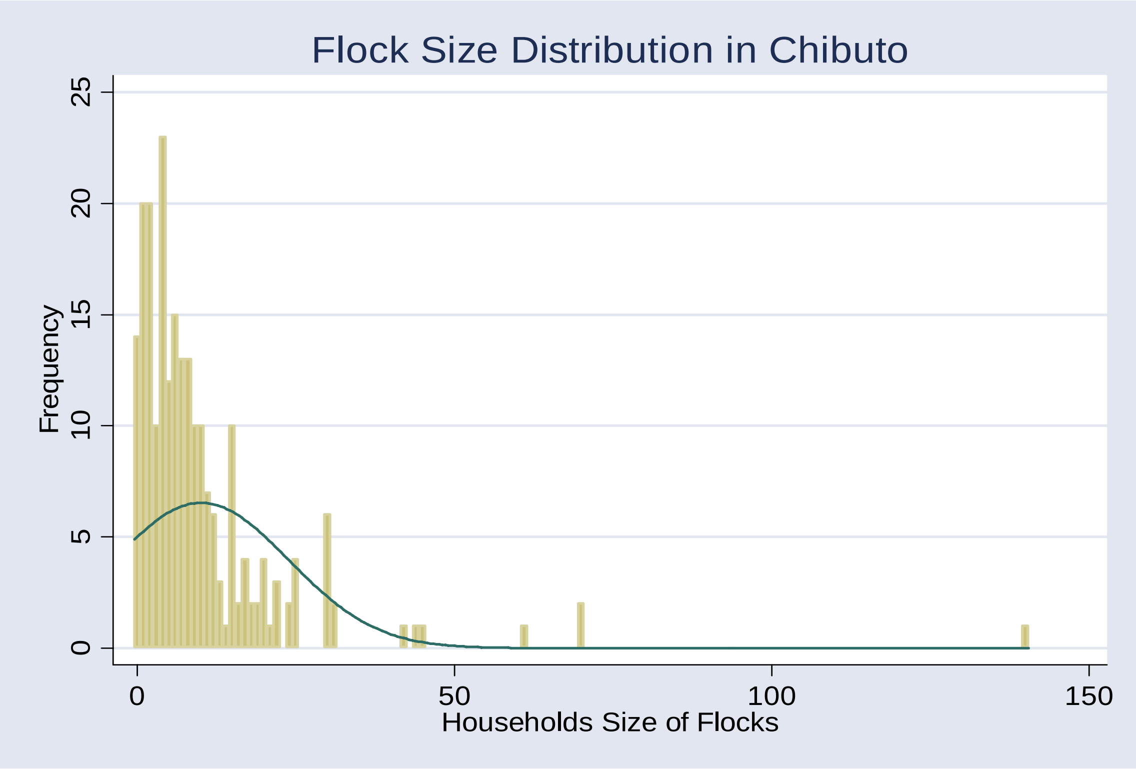

Figure 5: Distribution of Flock Size in Chibuto (Data Source: Chibuto household survey in 2007)

In addition, data collected in Chibuto district show that the flock size has a skewed distribution, with many households having small flock sizes (Figure 5). This suggests that the conventional mean is not a good measure of a typical flock size. To overcome this problem of asymmetric distribution of the flock size across the households in the deterministic as well as stochastic analyses, six categories of households were created based on the size of their flock, and the mean and standard deviation of flock size. The proportion of households in each category was calculated based on survey data collected in Chibuto district (Table 4). The overall incremental benefit at household level is given by the sum of individual category benefits weighted by the respective proportion of households.

Table 4: Definition of Households Categories Based on the Flock Size Distribution in Chibuto

Size of Flock Category	Size of Flock Average	SD	Proportion of Households	Mortality Rates Level	SD
Category 1 (0-5 Chickens)	2.4	1.6	44%	33%	28%
Category 2 (6-10 Chickens)	7.8	1.4	27%	80%	4%
Category 3 (11-15 Chickens)	13.0	1.7	12%	88%	2%
Category 4 (16-20 Chickens)	18.1	1.5	6%	92%	91%
Category 5 (21-25 Chickens)	23.5	1.6	4%	94%	<1%
Category 6 (26 or more Chickens)	41.0	15.5	6%	96%	1%

Data Source: Survey in Chibuto District in 2007 and Group Discussion in 2008

3.8.1.2. Determination of Incremental Benefits of Vaccination

From the outputs of adapted VIPOSIM, the net benefits in each season for a given initial flock size category are computed as:

$$NB_i = B_i^{wi} - B_i^{no} - C_i \qquad (1)$$

where NB_i is the annual net benefits of ND control at farm level in season i, in (MTN);[9]

B_i^{wi} are the benefits (total value of off-take in MTN) for the “with-control” situation in season i; B_i^{no} are the benefits (total value of off-take in MTN) for the “without-control” situation in season i; C_i are the additional costs related to technology use that were incurred in season i (costs of vaccination in MTN.)

From the net benefits determined for each season, and assuming that the interest is compounded quarterly given that a production season takes about 3 months, the total

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[9] There are approximately 25MTN per US Dollars

present value for the whole period of three years in a given category of flock size is calculated as (Hoy *et al*., 2001):

$$PV = \sum_{i=1}^{12} \frac{NB_i}{\left(1+\frac{r}{4}\right)^i} \tag{2}$$

where PV is the total present value of the net benefits obtained during the three years of simulation in MTN; NB_i is the net benefit in season i in MTN; and r is the discount rate. A discount rate of five percent is used; according to T. Walker (personal communication, May 11, 2009), this rate is increasingly common in the literature[10]. The annual net benefits at farm level for a given initial flock size category are determined as (Ross et al. 2008):

$$ANB = PV * \left[\frac{1-\frac{1}{(1+r)^T}}{r}\right]^{-1} \tag{3}$$

where ANB is the annual net benefit in MTN; T is the number of years, and T=3 in this based on the length of a simulation in VIPOSIM; and r is the discount rate. The overall annual net benefit of chicken vaccination per household is computed as:

$$VB = \sum_{i=1}^{6} ANB_i * \Pr_i \tag{4}$$

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[10] Thomas Walker, email to author, 11 May 2009

where VB is the overall annual net benefit per household in MTN; ANB_i is the annual net benefit for a category of flock size i in MTN; and $\Pr_i$ is the proportion of households in the category of flock size i.

3.8.1.3. Risk Analysis

There is uncertainty about some of the relevant variables used for computation of the benefits at farm level. One such variable is the without-control ND mortality rate in Mozambique, for which information is limited. For the deterministic analyses, to deal with the uncertainty involved, the sensitivity of the annual net benefits at farm level to the assumptions about levels of ND mortality is evaluated.

Twenty scenarios of without-control ND mortality levels were defined (19 hypothetical plus the base scenario, varying from 5 percent to 95 percent, with the base at 63 percent) and their respective benefits estimated. Since for a given overall mortality level, the mortality level is expected to vary across the categories of households and chickens (larger flock sizes categories tend to have relatively higher rates of infection), for each assumption of overall level of mortality, mortality level in each category of household is calculated based on household data set from Chibuto, then the calculations across birds categories are based on the relationship of disease mortality rates between chickens categories from Asgedom (2007). For stochastic analysis, to deal with risk, the ND mortality rate is treated as random variable.

Another key variable in the benefits estimates is the price of chickens. This becomes even more important to evaluate because there might be price effects due to technology use. Thus, sensitivity to prices is also evaluated for deterministic analysis. The analysis determines how much the price of chickens can decrease without affecting the overall farm level profitability of vaccination.

3.8.2. Measurement of Returns to Investments in ND Control Program

Aggregate analysis of the returns to investments in ND control is performed in two levels: the district level and a more aggregated level of analysis which includes all the 44 districts where the program is currently implemented. All the analyses are heavily based on data collected in Chibuto. Data such as the costs of extension, the parameters of chicken production and the levels of ND mortality among other information used in the aggregate analysis may be different from one district to another, but data for each of the districts covered were hard to obtain. Thus, parameters from Chibuto are mainly used as general parameters to get overall values. Both stochastic with ND mortality levels treated as random variable and deterministic analyses are also considered in those levels of analysis.

3.8.2.1. Deterministic Measurement of the Returns to ND Control

At the aggregate levels of analysis, the benefits of vaccination for each year depend on aggregate adoption rates, the magnitude of the shift of the supply curve due to the use of the technology, and elasticities of supply and demand. Logically, the increase of supply would influence the price in the market; however, the data on elasticities are not available for those calculations. Therefore, to simplify the analysis, a constant chicken price is used, and the sensitivity of the results to chickens prices is evaluated. The benefit-cost method is used for the measurement of the benefits at these levels with the underlying assumptions that demand is perfectly elastic, supply is perfectly inelastic, the demand and supply curves are linear, and the shift in the supply curve due to the use of the technology is parallel. Then, a sensitivity analysis is conducted on how much the price can fall without affecting the overall profitability of the program.

The likely extent of adoption of technology has a strong influence on the efficiency of investments; the benefits will be zero if the technology is not adopted. On the other hand, due to the time value of money, the longer the technology takes to be adopted, the higher are the initial research and development costs relative to the benefits, and consequently the lower are the net benefits (Batz et al. 2003).

There are two possible ways that the adoption rates can be considered for the analysis: in terms of the proportion of farmers using the technology or in terms of the proportion of chickens vaccinated. However, as previously mentioned, it is very difficult to obtain detailed and complete data on the flock size and number of chickens vaccinated in all campaigns. As a result, it is difficult to implement the second approach. Another reason to use the proportion of farmers using the vaccine as the adoption rate is because the farmers are not making the decision to vaccinate less than 100% of their chickens; they vaccinate as many as they can catch when they have access to the vaccine, and some of non-vaccinated chickens in a flock may also get protection against ND through transmission of vaccine virus from the vaccinated chickens. Thus, in this study the diffusion of the technology is considered in terms of the proportion of farmers using the technology on their flocks.

The other component to consider in the determination of aggregate net benefits of I-2 vaccine production and extension is the cost. The types of costs included are different in the two aggregate levels of analysis. The district analysis will only include vaccine extension costs while the more aggregated level of analysis will also include vaccine production costs.

For the estimation of profitability measures, the length of the period of analysis and the discount rates are the other components that need to be considered. Taking into account that 20 years is a reasonable lifetime for the equipment (vaccine production and refrigeration equipment), this study covers a period of 20 years starting from 1999, the year production of I-2 vaccine started in Mozambique. According to Gittinger (1982) for economic analysis the “opportunity cost of capital”, i.e. the return on the marginal investment made that uses up the last available capital, is the best discount rate. However, no one really knows what the opportunity cost of capital is (Gittinger 1982). In this study a social discount rate of five percent per annum is used. According to T. Walker (personal communication, May 11, 2009) this rate is increasingly common in the literature. The discount rate is incorporated when estimating these benefits over time.

3.8.2.1.1. Estimation of Benefits of ND Control at the Aggregate Level

The annual benefits of vaccination at aggregate levels are given by aggregating of the net benefits from all adopters of the technology in the level of analysis. The annual benefits are computed as:

$$\mathrm{B}_t^j = ANB * \mathrm{HA}_t^j = ANB * y_t^j * \mathrm{H}C_t^j \tag{5}$$

where B_t^j is the annual benefits of vaccination for the aggregate level j during the year t (in MTN); ANB is the overall annual incremental benefits per household in MTN; HA_t^j is the number of households using the vaccine in the level of analysis j during the year t;

y_t^L is the proportion of households who use the vaccine in level j during the year t; HC_t^L is the number of households who raise chickens in the level j during year t; and j is either the district level or the sum of all 44 districts where the vaccine is currently used.

Estimation of Adoption Patterns

The adoption rate at a certain point of time is given by the ratio between the number of households participating in the ND control program and the total number of households who raise chickens.

$$y_t = \frac{n}{N} \tag{6}$$

where n is the number of farmers who vaccinate their chickens and N is the number of farmers who raise chickens.

Since the adoption rates over time are only known in Mozambique for a limited number of years, the diffusion of the technology through time will be estimated using the methodology described by Morris and Heisey (2003). The estimation of diffusion patterns is based on the assumption that the cumulative proportion of households adopting I-2 vaccine follows an S-shaped or logistic pattern. This pattern is commonly used in adoption studies and mathematically is described as:

$$\mathrm{Y}_t = \frac{L}{1+e^{-a-bt}} \tag{7}$$

where Y_t is the cumulative percentage of adoption at time t; L is the upper bound of adoption (ceiling); a is a constant related to the time when adoption begins; and b is a constant related to the rate of adoption. According to Morris and Heisey (2003), given sufficient observations on Y_t , it is possible to estimate the unknown parameters L, a and b using non-linear regression methods. In cases where at least three observations of Y_t , are available, and L can be obtained independently, an ordinary least squares (OLS) regression can be used to estimate a transformed version of the logistic curve:

$$\ln\left(\frac{Y_t}{L - Y_t}\right) = a + bt \tag{8}$$

Logistic diffusion curves are appropriate for situations where there is a large and non-homogenous population of potential adopters who have unequal access to information about innovations and who differ on their willingness to innovate (Morris and Heisey 2003). This condition may hold for the case of diffusion of the I-2 vaccine for village chickens, which involves a large number of small-scale farmers with different levels of access to the vaccine. In this study, the diffusion curve is estimated using a few adoption points based on TIA data (TIA 2003, TIA 2005 and TIA 2006). Different ceiling levels L are assumed. Sensitivity to those assumptions is evaluated. However, provincial adoption rates are used instead of district rates, because TIA data estimates are not representative at a more disaggregated level. For Chibuto district level analysis the adoption rate is computed based on adoption in Gaza province, while for the more aggregated level of analysis, adoption rate across the five provinces (Gaza, Inhambane, Tete, Zambézia and Nampula) is used. The results of estimation of the rates of adoption are presented in Tables A 2 and A 3, and Figures A 1 and A 2 in the Appendices.

Projection of Number of Households Raising Chickens

Census and TIA data are used to compute the number of households raising chickens in a given level of aggregate analysis. First, based on Census data on household numbers in 1997 and 2007, the number of households is projected for each year over the period of study using the formula:

$$\mathrm{H}_t = (1+k)\mathrm{H}_{t-1} \tag{9}$$

where H_t is the number of households in year t; H_{t-1} is the number of households in the year previous to t; k is the rate of increase in the number of households from year to year. This rate is assumed to be constant over the period of analysis. Estimations resulted in a rate of 3.9 percent at the district level and three percent for the overall area covered by the vaccination program.

Then, the number of the households raising chickens for each year in a given level of analysis is determined as:

$$\mathrm{H}C_t = \alpha \mathrm{H}_t \tag{10}$$

where $\mathrm{H}C_t$ is the number of households raising chickens in year t and H_t is the number of households in year t; α is the average rate of ownership of chickens in the specific level of aggregation (computed from available TIA data sets: TIA 2002, TIA 2005 and TIA 2006). α is assumed to be constant over the years of analysis. See the results of estimation of the total number of households and households raising chickens in Table A4 and figures A 3 and A 4 in the appendices.

3.8.2.1.2. Estimation of the Costs of the Vaccination Program

To estimate costs of extension of the vaccine at the district level, information provided by CSL and other institutions involved in the program is used. The costs of equipment for vaccine conservation, extension material and vaccinators training were estimated based on aggregated information provided by CSL. Given the problem of limited and seasonal employment of vaccinators, there is a high risk of loss of trained vaccinators; thus, it is assumed that there will be a major vaccinator training every three years. Also, the regular extension costs associated with transportation of the vaccine to the communities during the vaccination campaigns or for visits for assistance in other periods, as well as costs of transportation of the vaccine from SPP to the district are included. In addition, salaries of staff involved in the vaccination program are included, and it assumed that these workers spend a quarter of the year devoted to the vaccination program during each year. See Table A 5 for estimated costs of extension.

The extension costs at the national level are estimated through aggregation of the district level extension costs over the 44 districts involved in the vaccination program. It is recognized that the costs of extension may vary considerably from one district to another according to the size of the population and distances covered. However, it is hard to obtain cost data; so values estimated here are used just to give a general picture. At this level of aggregate analysis, costs of production of vaccine (including quality control and packaging) and transportation of the vaccine to the provinces are also included. Computation of these costs is based on the estimates of SANDCP (2003). This author estimated the costs per dose of the vaccine in Mozambique. See the estimated costs in Table A 5, in the Appendices. The total costs of production and transportation of the vaccine to the provinces per year is based on the amount of the vaccine produced in the respective year. The amount of the vaccine produced per year is based on information provided by IIAM. For the years in which this information is not available, it is estimated based on average yearly increase of production. For number of doses of vaccine produced per year, see Table A 6 in the Appendices.

3.8.2.1.3. Measurement of Economic Profitability

The profitability analyses are carried out to assess the economic viability of the program. In this study, NPV and IRR are estimated. As previously mentioned, to account for the time value of money during the 20 years of analysis, a discount rate of five percent is used. NPV is equal to a flow of net benefits (benefits minus costs) discounted by the discount rate:

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} \tag{11}$$

where B_t is the benefit in year t; C_t is the cost in year t and r is the discount rate. If the NPV is positive, then the investment is considered profitable.

IRR is the return to the money invested; it is the rate of return that makes the present value of benefits equal to the present value of costs (NPV=0). When the IRR equals or exceeds the true opportunity cost of capital, project returns are large enough to cover all operating costs, pay back the principal on the capital invested in the project, and give an annual average return equal to IRR. The investment is considered profitable if and only if the resulting IRR is higher than the opportunity cost of capital.

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1 + IRR)^t} = 0 \qquad (12)$$

3.8.2.1.4. Sensitivity Analysis

Sensitivity of the estimated profitability measures to adoption ceiling level and ND without-control mortality levels is evaluated. For this evaluation, the annual net benefits estimated at farm level for each of the 20 scenarios of without-control ND rates are used to estimate the aggregate level profitability. In addition, analysis is completed to evaluate the degree to which the price of chickens can decrease as a result of technology use without affecting the overall profitability of the program.

3.8.2.2. Stochastic Analysis of the Returns to ND Control

The procedures for stochastic analysis of the returns to vaccination are similar to those used in the deterministic analysis. However, in the stochastic analyses, I use the stochastic annual farm level benefits that were determined, treating ND mortality levels as random variables, rather than using deterministic annual farm level net benefits.

CHAPTER IV: RESULTS OF ANALYSES OF IMPACT OF ND CONTROL

4.1. Benefits of ND Control at Farm Level

4.1.1. Deterministic Incremental Net Benefits at Farm Level

The results of the deterministic analyses for the base scenario (without-control ND mortality rate of 63 percent, prices per bird of 22 MTN for pullets and cockerels and 33 MTN for adult chickens and a price of 1.3 MTN per egg), suggest that vaccination of chickens against ND using I-2 is financially profitable for the farmers. As seen in Table 5, regardless of the flock size category, the overall incremental net benefits due to vaccination against ND at farm level are positive. This result is consistent with the findings of Asgedom (2007), who used VIPOSIM to analyze the farm level impact of different interventions in a village poultry production system, and found that ND vaccination resulted in higher net returns than housing intervention in the Ethiopian context. These results are also consistent with the findings from Udo et al. (2006) and Woolcock et al. (2004), who found that ND control has a positive effect on bird off-take, egg production, egg off-take and flock size.

Table 5: Annual Incremental Benefits and Costs of ND Control at Farm Level

Flock Size Category	Annual Net Benefits (MTN)	Annual Costs of Vaccination (MTN)
Category 1 (0-5 Chickens)	269	40
Category 2 (6-10 Chickens)	494	42
Category 3 (11-15 Chickens)	607	50
Category 4 (16-20 Chickens)	756	62
Category 5 (21-25 Chickens)	789	64
Category 6 (26 or more Chickens)	1179	93
Overall Benefit at Farm Level	**481**	47

Data Source: Estimations from VIPOSIM simulations

In general, vaccination of chickens using the I-2 vaccine results in a 481 MTN (equivalent to 19 US dollars) increase in household annual poultry income. According to Mather et al. (2008), the median net total income per adult equivalent (AE) in rural households was about 1,723 MTN in 2005 (corresponding to 6,892 MTN per household on average). This suggests that vaccination results in an increase of about seven percent in the total household income. This is a substantial improvement in a rural household's income, considering that it requires very low investment. Farmers need to invest about 47 MTN per year per flock, which is less than one percent of the median total household income. In general, vaccination of chickens results in about 10.3 MTN per one MTN invested at the household level. This results in about 1030 percent annual rate of return, which is very high. Additional analysis suggests that in general, farmers' investments in chicken vaccination will be profitable as long as the cost of vaccination per bird is less than or equal to 5.6 MTN which is more than 11 times the actual vaccination cost of 0.5 MTN per bird.

As the results suggest, farmers' investments in the vaccination of their chickens is clearly justified by the returns. However, cash investment in the vaccine may be a constraint for vaccine adoption by the poorest group of farmers for whom this investment corresponds to about 14 percent of their household income (Mather et al., 2008). Giving those farmers opportunities to pay for vaccination in chickens instead of in cash, may be one way to overcome the problems of lack of cash for vaccine payments, especially because the vaccinators turn out to be one of the biggest poultry producers in the communities.

These findings suggest that there are financial incentives for the farmers to invest in the vaccination of their chickens, and that farmers just need opportunities to realize the benefits. The success in increasing the rates of use of I-2 appears to depend on extension strategies and distribution of the vaccine to the final users, in which DNER and DINAP play major roles.

Vaccination of chickens is also expected to have a positive effect on gender equality. It is commonly argued that poultry production plays a very important role in promotion of gender equality because many women participate in poultry production. According to Mather et al. (2008) female- and widow-headed households in Mozambique tend to have fewer economic opportunities and lower asset levels, and both female- and widow-headed households are more likely to be found in the lower income quintiles. Women are usually less educated and they usually have fewer skills and fewer assets than men, which limit their participation in income-earning activities and formal employment. Chickens provide women an opportunity to generate income. However, data available for this study are not sufficient to give conclusive evidence about the effect of vaccination on improvements in women's income. The potential for women to earn income from chicken vaccination programs, not only depends on their participation in the production process, but also on intra-household arrangements. Women can only benefit from the technology use if they have the power to make decisions about production, consumption, sales and the use of income generated. Further research may be performed to evaluate the impact of the program on gender equality.

4.1.1.1. Sensitivity of Net Benefits at Farm Level to ND Mortality Levels

Performing sensitivity analysis of the adapted VIPOSIM simulations for a range of without-control mortality rates, as indicated earlier, results suggest that the annual incremental benefits at the farm level are sensitive to without-control mortality levels. As the overall level of without-control mortality increases, the overall incremental benefits also tend to increase (see Figure 6). For lower without-control mortality levels, the benefits of vaccination tend to be lower. This result was expected, since in places where the ND mortality rate is higher, the vaccine is expected to save more chickens than in places with a lower ND mortality rate. This result suggests that in the process of expanding the vaccination program, priority should be given to areas where ND mortality rate is currently very high.

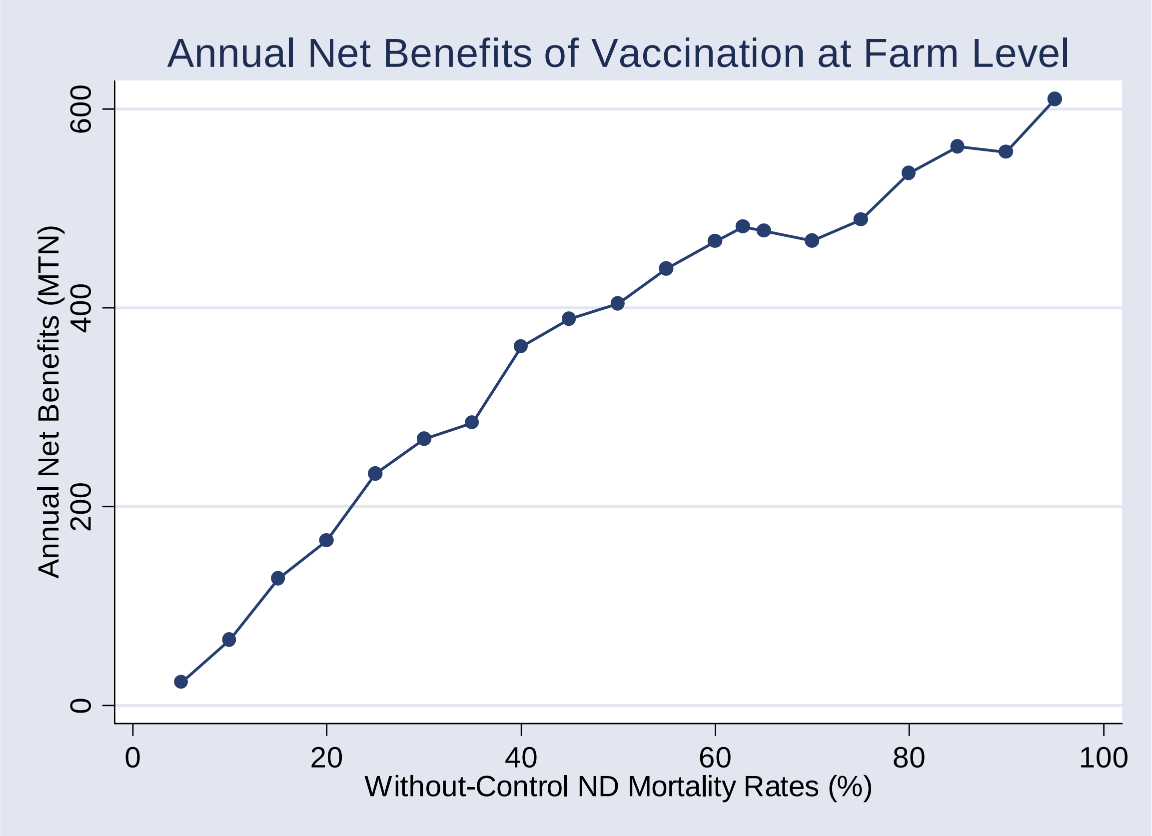

Figure 6: Sensitivity of the Annual Net Benefits at Farm Level to Without-Control ND Mortality Levels (Data Source: Author Estimations)

However, as shown in Figure 6, the net benefits do not increase linearly or smoothly as the ND without-control mortality levels increase. The explanation behind this relationship between the ND mortality level and the level of annual net benefits has to do with the VIPOSIM model design, which implicitly imposes the level of availability of the scavenging resource base, by setting the threshold flock size above which all the chickens are sold or consumed in the model. According to the law of decreasing marginal productivity, given the level of available scavenging resources, the higher the number of chickens, the higher is the competition among birds for scavenging resources and the lower is the productivity. Thus, VIPOSIM forces higher levels of off-take when the flock reaches those threshold limits. Then, it is necessary to allow some time without off-takes in order to build up the flock. Controlling ND for higher levels of ND mortality implies saving a relatively higher number of chickens, and consequently larger flock size than in situations of lower ND mortality. However, the amount of scavenging resources available for feeding is the same (same threshold levels) in both situations.

Looking at the household level results in greater detail (Table A 7), regardless of the overall without-control level of mortality, households with larger flock sizes in general tend to get relatively higher annual net benefits, as was indicated in Table 5 for the base scenario. This result was expected, since the vaccine saves more chickens in households with large flocks than in households with small flocks. In addition, Table A 7 reveals that the net benefits can even turn out to be negative for households with smaller flock size (0 to 10 chickens) when the without-control mortality levels are very low; however, regardless of the flock size category, all farmers benefit from vaccination when the overall without-control ND mortality level in the region is greater than or equal to 40 percent. Since in most cases, chickens are the only asset owned by the poorest farmers, vaccination of chickens will result in additional income that will help to lift some of those families above the poverty line. This finding supports the theory that vaccination has the potential to reduce absolute poverty, particularly for Mozambique where the ND is endemic and causes severe losses annually, and a large percentage of the rural population is involved in chicken production.

4.1.1.2. Sensitivity of Incremental Net Benefits at Farm Level to Prices

As previously mentioned, the increase in the supply of chickens as a result of vaccination may have effects on chicken prices. Results of the analysis of the net benefits as chicken prices are progressively reduced, *ceteris paribus*, show that the net benefits become zero only if the price becomes nine percent of the original price used in the analysis; the price can fall by as much as 90 percent without affecting the overall profitability of the vaccination. This result suggests that the overall profitability of vaccination at the farm level is not very sensitive to price changes. Only in the extreme case of almost perfectly inelastic demand for village chickens would the increase on the supply as a result of vaccination result in negative returns, but this is not likely.

A current and interesting debate in the poultry industry in Mozambique is related to the arrival of very cheap Brazilian frozen chicken in Mozambique as a result of excess production in Brazil and possible “dumping”. There is an increasing concern about how the “dumping” of Brazilian poultry might affect the local poultry industry and technological interventions in the sector.

Even though this aspect was not directly addressed in this study, it can be said that it may constitute a big concern to caged poultry and commercially oriented system; however, it does not constitute a big concern either for village poultry production system in general, or for adoption of vaccination program, for several reasons. First, village poultry has a completely different market than imported Brazilian chicken. Improved commercial chicken is mainly available and consumed in urban areas while village chickens are mostly consumed by the rural population, and usually the producer is also the consumer of village chicken.

With an underdeveloped transportation infrastructure, Brazilian chickens are unlikely to reach many rural areas. In the event of reaching rural areas, they will have a minimal effect on the village poultry market because the sales prices will be higher than in urban areas due to transport and marketing costs. Also, in rural areas the majority of the farmers are not commercially oriented; they are more interested in ensuring their subsistence. Usually they do not have cash available to purchase goods, and they mostly consume what they produce.

On the other hand, village chickens that are supplied to urban areas are used mainly for very specific activities (e.g., cultural ceremonies) for which Brazilian chicken cannot be used as a substitute. In addition, village chicken is more flavorful than commercial chickens such that urban families are sometimes willing to pay a premium for village chicken.

Given that the price of village chickens can fall by as much as 90 percent without affecting the profitability of vaccination at the farm level, speeding up the adoption of chicken vaccination in order to increase the supply of village poultry in major consumption centers could be a valuable strategy to address the problem of Brazilian chicken “dumping” in the long term. The increase of chicken supply as a result of vaccination would reduce village chicken price and make it competitive with Brazilian chicken.

4.1.2. Stochastic Analysis of Incremental Net Benefits at Farm Level

As previously mentioned, @Risk software was used to generate the distribution of the results based on the best fit probability distribution to ND mortality rates data, and then the distribution of the net benefits was generated. Analysis suggests that the triangular distribution best fits the mortality data. Results of stochastic analysis treating the ND rates as a random variable show that there is a 90 percent probability that the values of the annual net benefits at farm level fall between 248 and 543 MTN (see Figure 7). This confidence interval covers the overall annual net benefit estimated using deterministic methodology. In addition, the results suggest that the most likely value of net benefits at farm level is 483 MTN per year, which is close to 481 MTN; the value estimated using the deterministic approach.

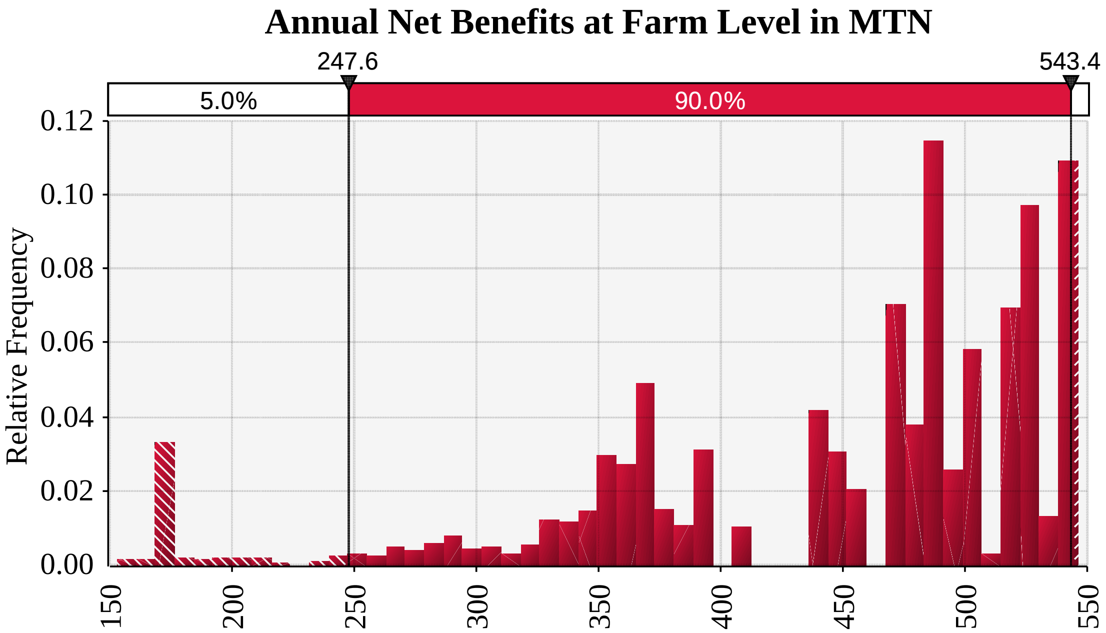

Figure 7: Distribution of the Overall Annual Net Benefits at Farm Level (Data Source: Author Estimations)

4.2. Profitability of Vaccination Program at District Level

Benefit-cost analysis at the district level was performed. Results of profitability measures over 20 years, assuming the level of ND mortality base of Chibuto (about 63 percent) and an adoption ceiling level of 50 percent, suggest that investment in extension and distribution of I-2 vaccine in the district is highly profitable (see Figure 8, and for more details refer to Table A 8, in the Appendices). These investments result in a NPV of about 34,662,840 MTN (1,386,514 US dollars) and an IRR of 37.39 percent.

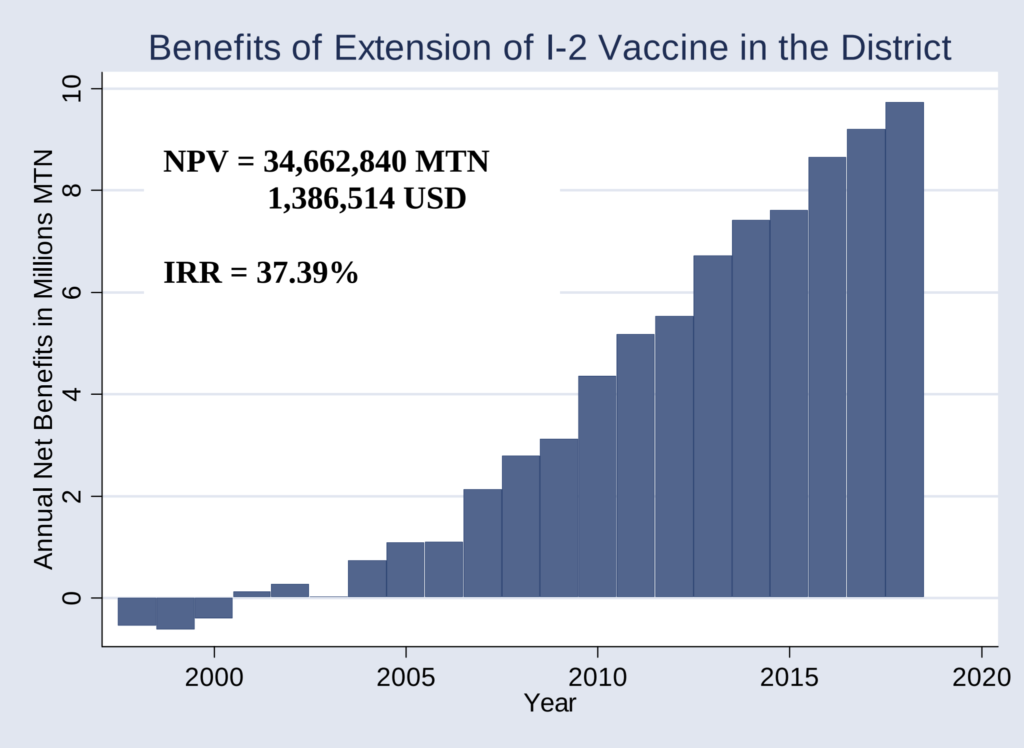

Figure 8: Benefits of Investments in the Extension of I-2 Vaccine in Chibuto District (Data Source: Author Estimations)

4.2.1. Sensitivity Analysis

As previously discussed, three types of sensitivity analysis were performed at the district level of analysis: sensitivity to ND mortality rates, ceiling level of adoption and chicken price. Results of the analysis suggest that the overall profitability of the vaccination program in Chibuto district is sensitive to the level of without-control mortality due to ND. The program is profitable when the overall level of mortality due to ND in the district is at least 10 percent (see Figure 9, and for more details refer to Table A 9 in the appendices). As the level of ND rates of mortality increases, the value of NPV also increases. This finding supports the idea that during the planning process of expansion of ND program to other sites, the levels of ND occurrence must be taken into consideration, and places with high levels of without-control mortality should be given priority.

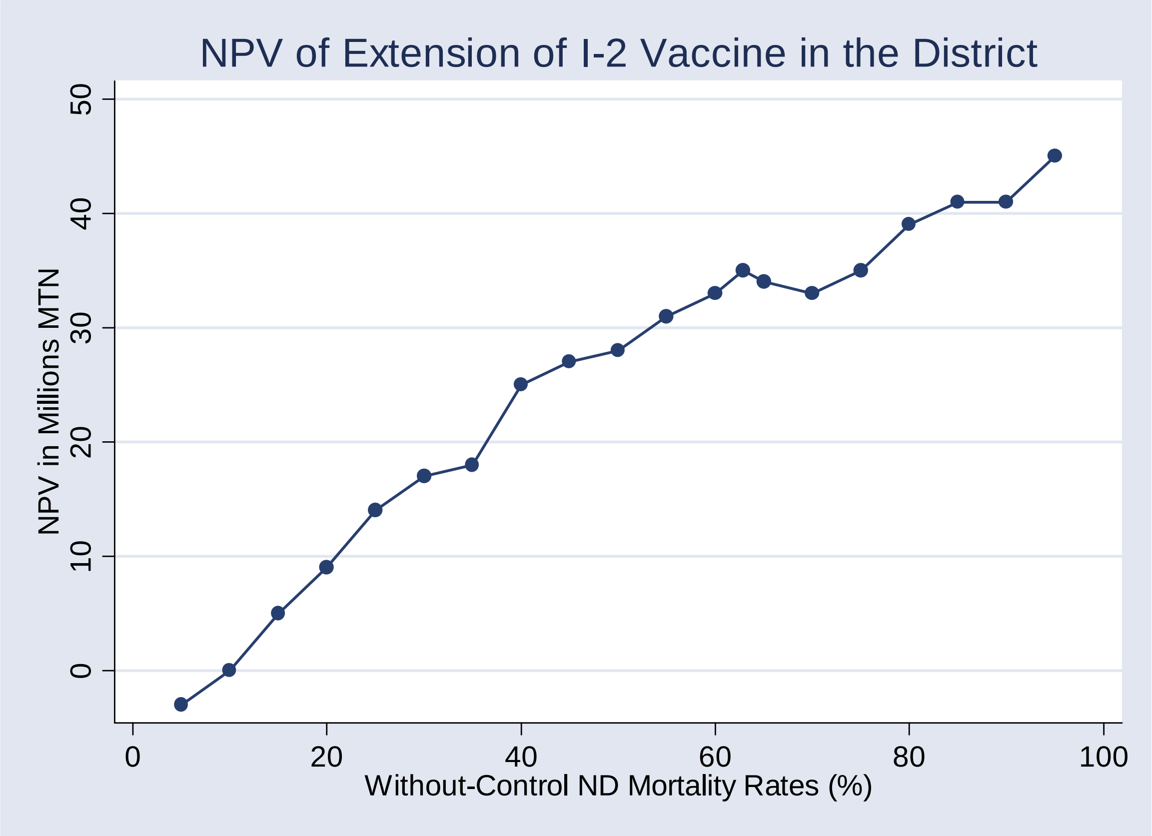

Figure 9: Sensitivity of NPV to Without-Control ND Mortality Rates in Chibuto (Data source: author estimations)

However, similar to the analysis at the farm level, the NPV does not increase linearly or smoothly as ND mortality rates increases. The justification of this problem is the same as the one presented at farm level analysis. Since the district level benefits are the aggregated benefits at the farm level, the results show the same trend.

Analysis of the effects of changing assumptions about the ceiling level of adoption of I-2 vaccine suggests that if at least 15% of farmers raising chickens in the district adopt the technology over 20 years, the vaccination program is profitable. The benefits tend to be higher as the adoption ceiling levels increase (see figure 10; for more details see Table A 10, in the Appendices). This suggests that efforts to reach the highest adoption level possible will maximize the profitability of the program.

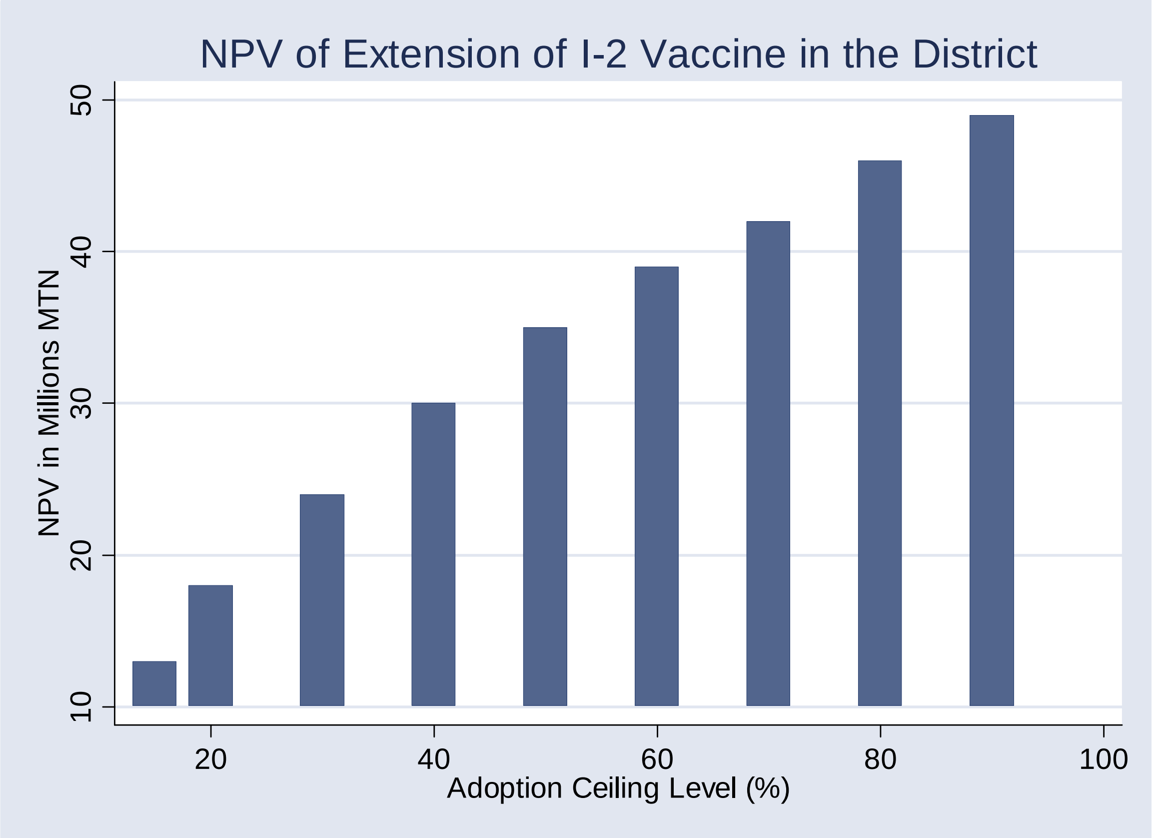

Figure 10: Sensitivity of NPV to Adoption Ceiling Levels in Chibuto (Data Source: Author Estimations)

Furthermore, sensitivity analysis of the profitability of the program to reduction in chicken prices at the district level reveals that the price can fall by as much as 79 percent, without affecting overall profitability of the program in the district.

4.2.2. Stochastic Analysis

Results of the stochastic analysis treating ND mortality rate as a random variable, and using triangular distribution (best fit distribution to ND mortality), indicate a 90 percent probability that the NPV at district level will lie between 15.36 and 39.80 million MTN, over the 20 years of analysis (See Figure 11). The deterministic value of NPV at district level also falls within the 90 percent confidence interval. In addition, the results indicate that the most likely NPV value over the 20 years is 34,823,553 MTN, which is also very close to 34,662,840 MTN; the value estimated using the deterministic approach.

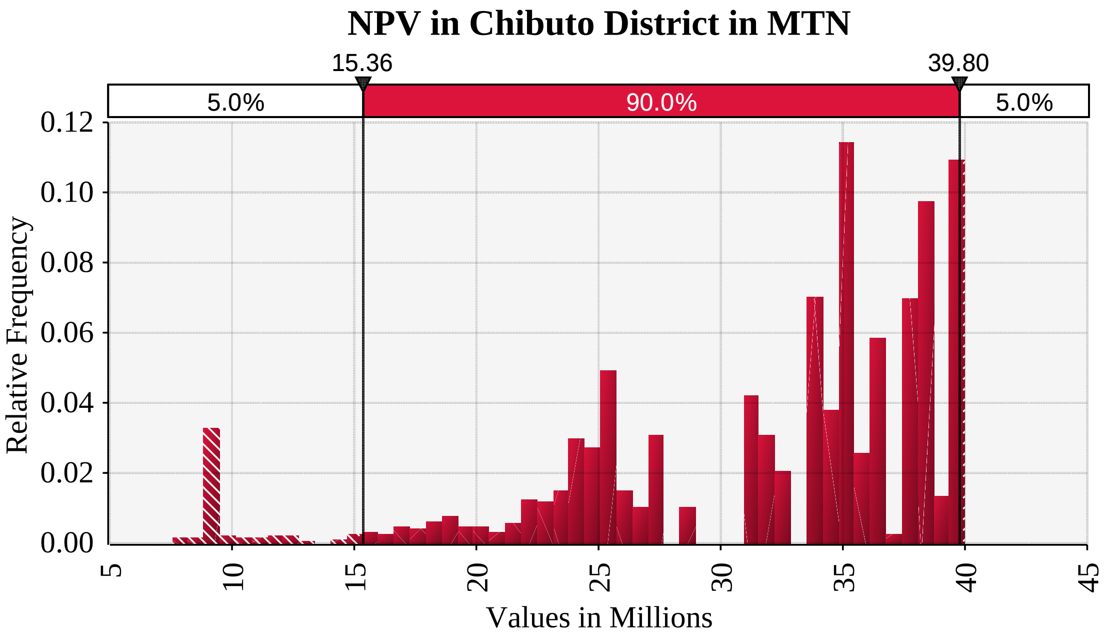

Figure 11: Distribution of NPV of Extension of I-2 Vaccine in Chibuto District (Data source: Author Estimations)

4.3. Profitability of Production and Extension of I-2 in Mozambique

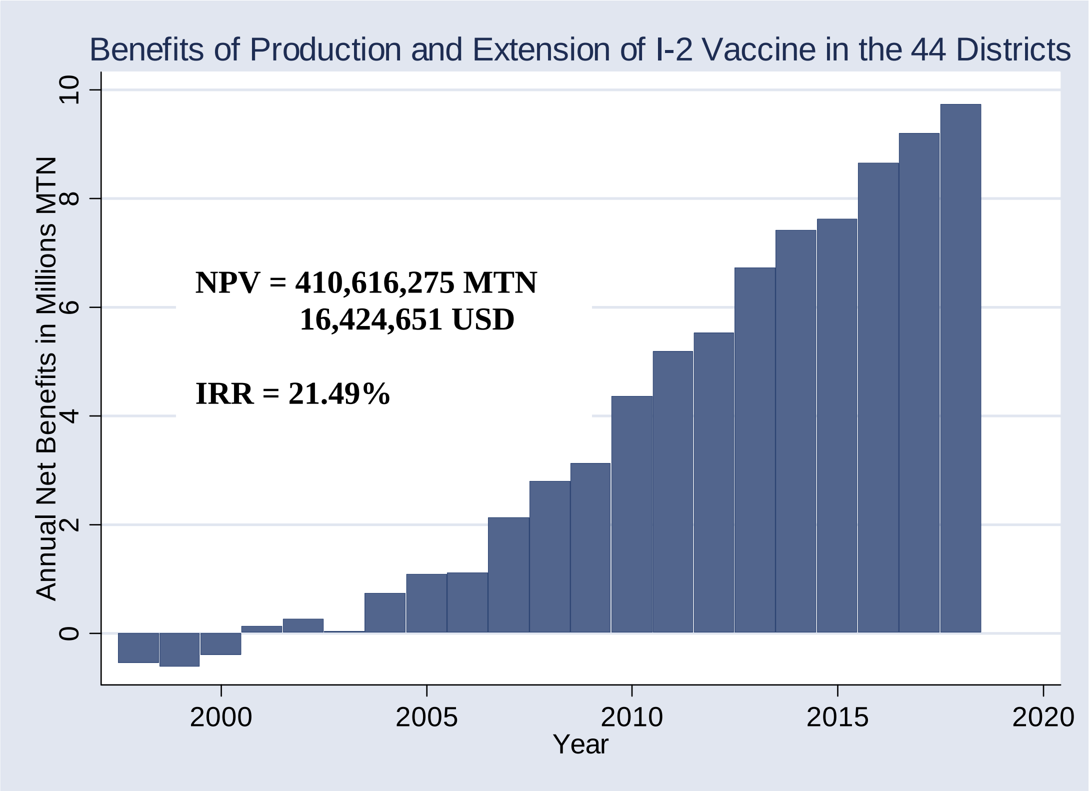

Figure 12: Benefits of Investments in the Production and Extension of I-2 Vaccine in the 44 Districts (Data Source: Author Estimations)

Assuming a ceiling level of adoption of 50 percent and the base scenario at farm level, production and extension of I-2 vaccine across the 44 districts of program implementation in Mozambique generate positive returns (see Figure 12, and for details see Table A 11). The NPV is about 410,616,275 MTN (about 16,424,651 US dollars) and the IRR is about 21.49 percent.

4.3.1. Sensitivity Analysis

The results of evaluation of sensitivity of profitability of production and extension of the I-2 vaccine across the 44 districts of implementation, suggest that it is sensitive to the level of overall without-control ND mortality in the communities. The program is profitable if the overall level of ND mortality is at least 25 percent in all the districts where the vaccine is already used (see Figure 13, and for more details, see Table A 12 in the Appendices). Thus, during the planning process of expansion of the ND program to other sites, the levels of without-control ND occurrence must be taken into consideration, and places with high levels of mortality should be given priority.

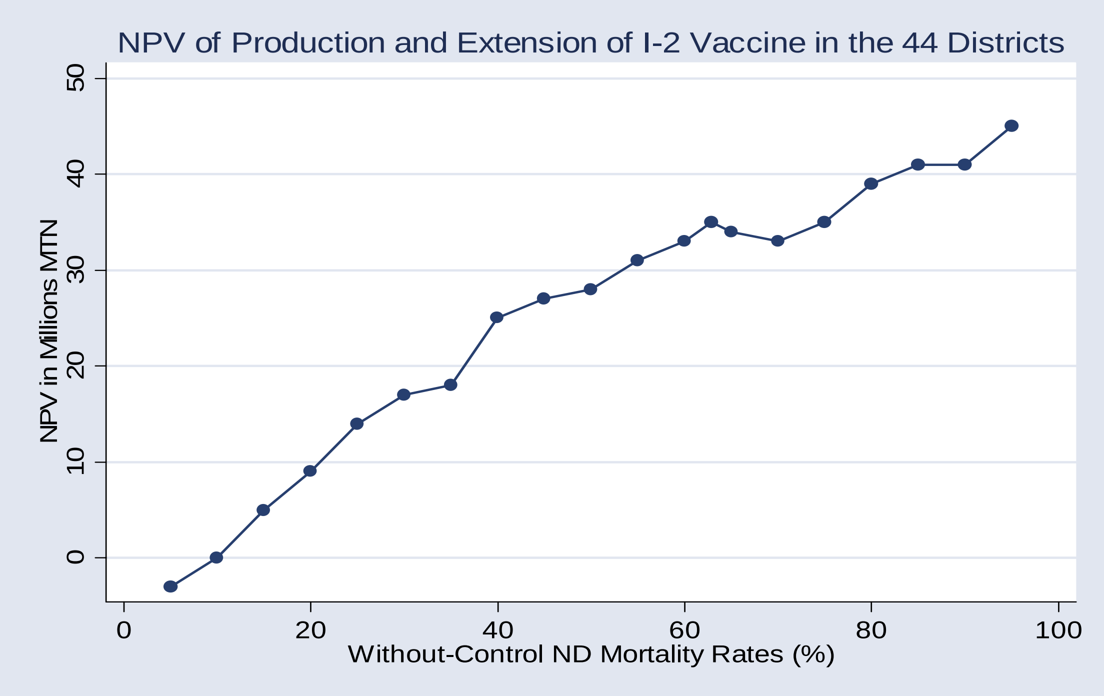

Figure 13: Sensitivity of NPV to Without-control ND Mortality Rates in the 44 the Districts (Data Source: Author Estimations)

In addition, assuming adoption ceiling levels of at least 10 percent over the 20 years, the program is profitable (see Figure 14 and other details in Table A 13). As the ceiling level increases, the benefits of the program also increase. This reinforces the idea that efforts towards reaching the highest adoption ceiling level possible will maximize profitability of the program in the long term.

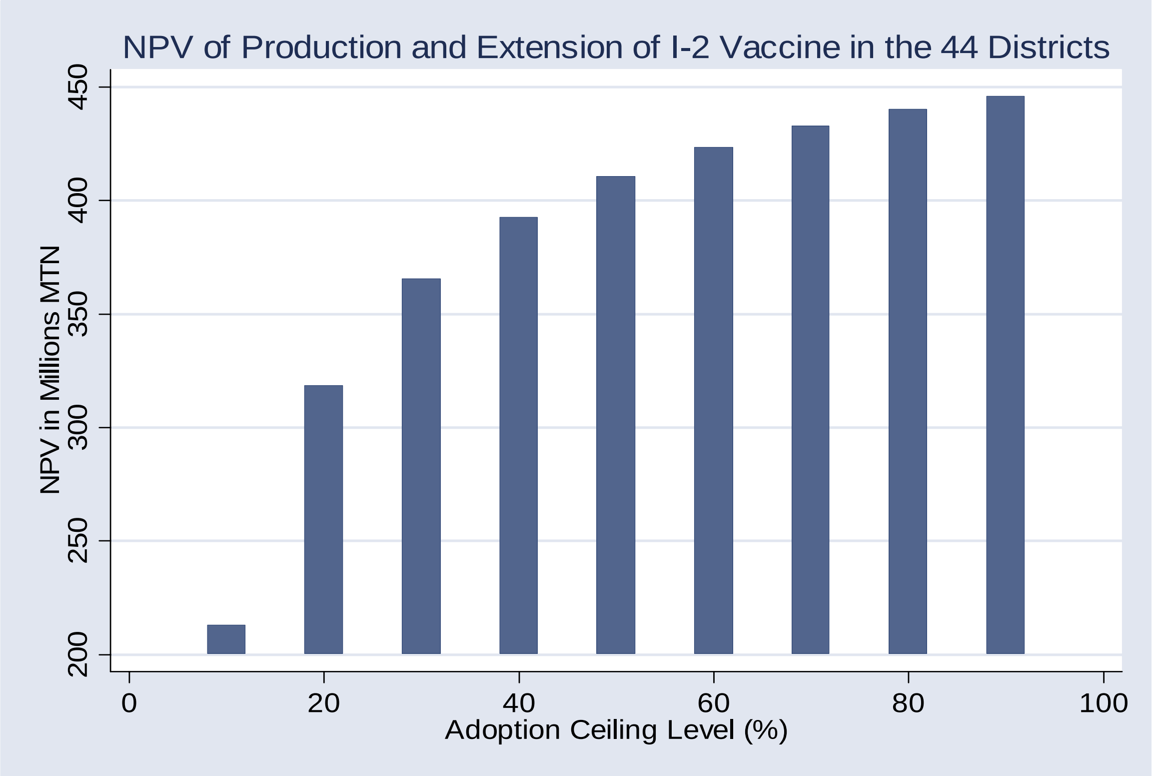

Figure 14: Sensitivity of NPV to Adoption Ceiling Levels in the 44 Districts (Data source: Author Estimations)

Additional analysis suggests that the price of chickens can decline by as much as 44 percent without affecting the overall profitability of the program in the areas of implementation.

The analysis of the vaccination program's impact in 44 districts shows that the program is very profitable. Given that the vaccine production facilities are currently operating below their capacity, expansion of the program to other districts is feasible, and it may result in higher profitability without major new investments in vaccine production infrastructure.

4.3.2. Stochastic Analysis

Results of analysis of distribution of NPV in the 44 districts of implementation treating ND mortality rate as random variable and using triangular distribution for the random variable, suggest that there is a 90 percent probability that the NPV of the vaccination program lies between 97 and 494 million MTN over 20 years (See Figure 15). Similar to the other two levels of analysis, the 90 percent confidence interval covers the value estimated using the deterministic approach. In addition, the results suggest that the most likely NPV value over the 20 years is 413 million MTN. The most likely NPV of production and extension of I-2 vaccine in the 44 districts is also close to the value estimated using the deterministic method which is 410,616,275 MTN.

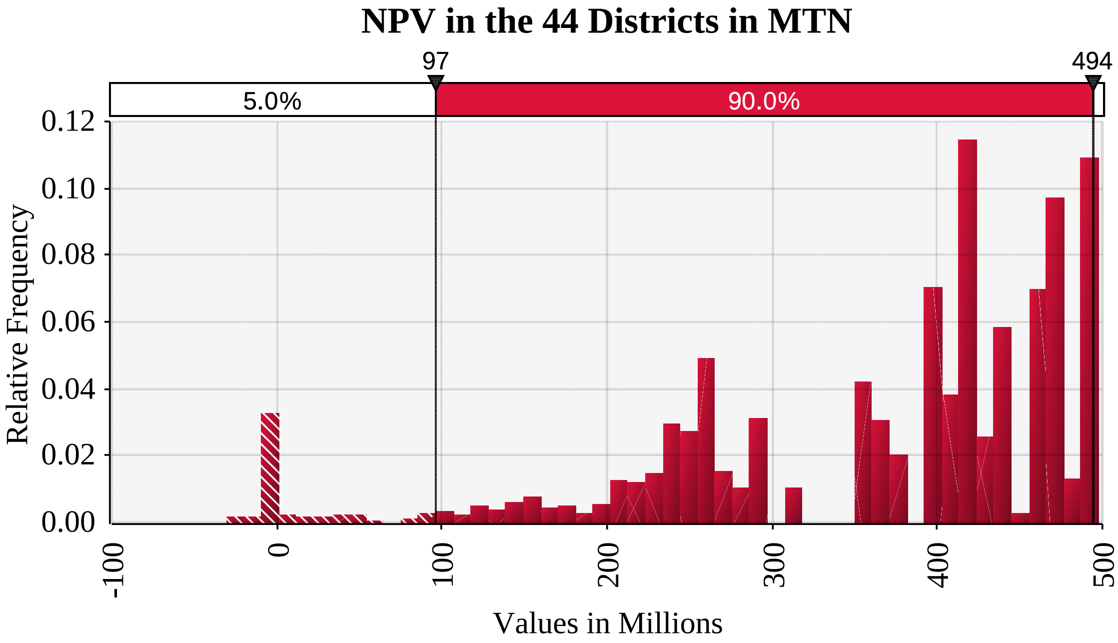

Figure 15: Distribution of NPV of Production and Extension of I-2 Vaccine in the 44 Districts (Data source: Author Estimations)

CHAPTER V: SUMMARY OF FINDINGS AND POLICY IMPLICATIONS

5.1. Findings and Policy Implications

Investments in ND control are financially profitable for farmers. Vaccination of chickens using the I-2 vaccine results in about 481 MTN (equivalent to 19 US dollars) increase in annual household poultry income. This income increase corresponds to about seven percent of average annual rural household income, for an investment of less than one percent of the income. Even if the vaccination costs increase, the program will still be profitable for the farmers, as long as the costs of vaccination per bird do not exceed 5.6 MTN.

There are financial incentives for the farmers to invest in the vaccination of their chickens, and farmers need to be informed about the benefits. Increasing the rates of use of I-2 vaccine mostly depends on the strategies of diffusion of information about the vaccine and distribution of the vaccine to the final users, in which DNER and DINAP play major roles.

The profitability of the program is sensitive to the incidence of without-control ND: the higher the mortality rate, the higher the benefits of vaccination. When planning expansion of the program to the other sites, prioritizing areas with high incidence of ND may constitute a good strategy for maximizing the impact of investments.

Regardless of the size of initial flock, the farmers can benefit from vaccination as long as the rates of ND mortality in the region reaches at least 40 percent. Chicken vaccination has a potential to reduce absolute poverty, particularly for Mozambique where ND is endemic and causes severe losses annually.

Looking at the aggregate levels, production and extension of I-2 vaccine has positive returns. Extension of I-2 vaccine in Chibuto over 20 years results in NPV of about 34.6 millions MTN. On the other hand investments on production and extension of I-2 vaccine in the 44 districts over 20 years results in NPV of about 410 million MTN. An increase in the adoption ceiling level results in relatively higher returns. The stochastic analyses result in estimates close to deterministic ones, and suggest that the results are not highly sensitive to the uncertainties of the various aspects. Therefore, expansion of the vaccination program to new areas should be explored and strategies put in place to speed up the adoption in areas already covered.

Partnerships between the Government of Mozambique, NGOs, and other private entities in delivering the vaccine to the final users are a good strategy to overcome public funding limitations for coverage of the vaccination program. However, there is a threat to the sustainability of the program in the long term related to this strategy. If for some reason the interest of the NGO or private company in participating in the program changes, the area where they have been operating may no longer have access to the vaccine, unless other options are developed. Thus there is a need to look for additional strategies as a complement in order to ensure long-term sustainability of the program.

Purchase of a new freeze dryer or repairing of broken one could increase the efficiency of production, and possibly, result in transportation efficiency in getting the vaccine to the provinces. Higher levels of vaccine production and transportation of larger quantities to the provinces may enable economies of scale to be realized, reducing the cost incurred per dose of vaccine. Also, with higher levels of production it may be possible to supply large-scale or regional poultry input markets, provided that the vaccine is commercially registered and quality guarantees are in place.

Making the vaccine available does not seem to be a sufficient condition for guaranteeing positive and sustainable results at the village level. Community leaders' involvement in the vaccination program is crucial for the success and sustainability of the ND control program. Getting community leaders and district administrators on board will speed up the adoption of the vaccine in the district if they raise awareness of the problem of ND and the importance of vaccination in public community meetings.

The seasonal nature of the vaccinator's job is a problem for the sustainability of the vaccination program. Vaccinators can easily quit the vaccination program in favor of better prospects. To enhance the performance and sustainability of the program, opportunities for other related income generation activities should be created for the vaccinators to occupy them during the off-season period, and to lessen the chance that they will commit themselves to other engagements when needed for the vaccination campaign.

We cannot conclude from this study about the impact of the vaccination program on promotion of gender equity. The potential for women to earn income from chicken vaccination depends not only on their participation in the production process, but also on intra-household arrangements. Women can only benefit from the technology use if they have the power to decide about production, consumption, sales and the use of income generated. While we know that women are active with poultry production, we do not have sufficient information on control of poultry marketing and financial resources.

5.2. Further Research

In this research it was found that whenever the levels of ND mortality rates are appreciable, ND control has positive returns; and it is argued that because village chickens are one of the mains assets owned by the poorest households, and ND is endemic in Mozambique, ND control will contribute to lift some households above the poverty line. However, there is no quantification of how much the poverty indicators will fall as a result of ND control. Further attention should be given to the quantification of impact of ND control on poverty indicators.

While performing the aggregate analysis of impact of I-2 vaccine use in the 44 districts of implementation, information believed to be related to agro ecology and husbandry conditions such as ND occurrence and chicken production and utilization parameters used was heavily based in data from one district because there was no information available about spatial distribution of the parameters across different agro ecologies and/or districts. Thus, further research is recommended on geographical distribution and intensity of ND in Mozambique, as well as spatial distribution of impact of ND control.

This research was not conclusive about the impact of the vaccination program on promotion of gender equality. There is insufficient information on women’s control of poultry marketing and financial resources. Further research is recommended on impact of vaccination on gender equality.

Also, no information about elasticity of demand for village chickens is available in Mozambique. This is needed for greater understanding of the possible price impacts of increasing village chicken production. Thus further research on marketing of village chickens is recommended.

APPENDICES

Table A 1: Average Chickens per Household and Total Chickens Vaccinated per Vaccinator in Each Campaign

Vaccinator	Mar-05		Jul-05		Nov-05		Mar-06		Jul-06		Nov-06		Mar-07	
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
A. Macie	.	.	.	.	.	.	.	.	.	.	16	415	14	1,045
A. Novela	7	33	10	70	17	50	8	421	11	545	14	723	16	679
A. Massingue	.	.	.	.	.	.	.	.	.	.	.	.	14	27
A. Ndove	9	175	12	169	10	105	7	257	9	242	11	159	11	56
A. Cuna	8	76	13	80	8	65	.	.	.	.	10	20	.	.
A. Chilaule	.		8	8	2	2	8	135	9	305	14	486	21	374
C. Mantchane	5	16	5	28	8	58	14	352	14	432	19	842	13	766
E. Mondlane	11	654	14	992	19	1,327	14	1,166	18	1,468	21	2,069	25	2,370
F. Chiconela	.	.	.	.	.	.	12	630	16	596	15	581	9	591
Filomena	9	423	11	515	10	434	11	232	12	950	12	803	10	407
F. Mucavel	.	.	.	.	.	.	8	407	9	296	10	411	17	422
G. Phacule	11	373	12	362	9	197	8	450	10	995	14	1,057	14	830
L. Mazivila	15	375	14	367	15	293	13	375	17	419	21	487	17	309
L. Saveca	16	49	13	39	.	.	14	162	14	256	19	439	28	689
M. Amelia	5	9	6	19	19	19	11	135	11	274	19	265	23	278
Miseria	.	.	.	.	.	.	.	.	.	.	.	.	14	920
N. Mbiza	11	226	13	241	12	254	11	328	10	302	12	524	15	380
Paulo	8	80	7	64	12	112	7	14	.	.	8	42	9	222
P. Covela	.	.	.	.	.	.	13	140	17	626	.	.	19	871
R. Richete	9	74	7	41	9	124	4	40	10	233	14	239	11	230
S. Sutho	19	354	20	383	14	170	15	642	20	511	18	703	16	581
Saquina	.	.	.	.	.	.	.	.	.	.	.	.	15	622
Xadreque M.	.	.	.	.	.	.	.	.	.	.	.	.	24	1,338
Zulmira	.	.	.	.	.	.	9	91	13	170	12	136	.	.

1 - Average number of chickens vaccinated per household per campaign

2 - Total number of chickens vaccinated per campaign

Source: Author Computations

Appendix A1: Mathematical Conceptualization of VIPOSIM (extracted from Asgedom 2007, 96-105)

1. Randomization

Random numbers were used as coefficients of standard deviations of average input values of explanatory variables to determine the different results of a given scenario. The random coefficients from a normal distribution were generated as:

$$R = \left(\sum_{12}^{1} Rand\ (\ )i\right) - 6 \qquad \text{(A1.01)}$$

where R is random coefficient and $Rand(\ )i$ is the ith random number in a normal distribution. The value of the explanatory variable is calculated as $\mathrm{X} = \bar{x} + (R * SD)$. If $\mathrm{X} < 0$, it is set to zero. In addition, for values presented in percentages, if $\mathrm{X} > 100\%$, it is set to 100%. If all SD values are set to zero, the model becomes deterministic instead of stochastic. It is also possible to enter zero for a single parameter, to exclude the variation in that parameter.

The standard procedure to deal with random variation of simulation, given the same input data, is to replicate the simulation a number of times and take the averages of a parameter. The number of replications required, $\mathrm{N}(m)$, is determined using initial replications:

$$\mathrm{N}(m) = \left(\frac{S(m) t_{m-1,1-\alpha/2}}{\mathrm{X}(m)\varepsilon}\right)^2 \qquad \text{(A1.02)}$$

where $\mathrm{N}(m)$ is the number of replications required, given m replications; $\mathrm{X}(m)$ is an estimate of the real mean μ from m simulations runs (samples); $S(m)$ is an estimate of real standard deviation σ from m simulations runs; α is the level of significance; ε is the allowable percentage error of the estimate $\mathrm{X}(m)$, $\varepsilon = |\mathrm{X}(m) - \mu| / |\mu|$. $t_{m-1,1-\alpha/2}$ is the critical value of the two-tailed t-distribution at a level α of significance, given $m-1$ degrees of freedom.

Using 10 initial sample runs, at 95% level of significance and 5% allowable error, the number of replication runs was calculated to be 50. The initial sample runs were performed using field data from Tigray, Ethiopia.

2. Initial flock

In the model, the flock categories are denoted as i, where i runs from 1 to 5 representing chicks, pullets, cockerels, cocks and hens, respectively. After entry of initial numbers, the random number of birds in category i in the initial flock (IFi) is calculated as:

$$IFi = CMi + (SDi * R) \tag{A1.03}$$

where CMi is the average number of birds in category i entered by the user; SDi is the standard deviation of the number of birds in category i entered by the user; and R the random coefficient of flock size.

3. Mortality

Mortality is considered to differ among categories of chickens and seasons. The variation of mortality can be entered by the user for j, representing four seasons. Mortality is distinguished between mortality due to diseases, predation or other reasons. The modeling procedure of mortality considers the different flock categories and year seasons categories.

The predation loss of a flock category is determined from initial number of birds, predation mortality rate (varied by SD and random number) and season:

$$P_{ij} = C_{ij} * \left(PR_{ij} + \left(R_{j} * SD_{ij} \right) \right) \qquad \text{(A1.04)}$$

where P_{ij} is the number of birds killed by predators in category i in season j, C_{ij} is the number of birds present in category i in the beginning of season j; PR_{ij} is predation rate (%) of category i in season j; SD_{ij} is the standard deviation of PR_{ij} ; R_{j} is a random coefficient in season j. The same random coefficient is used across mortality rates per season for each category because positive correlation was observed between parameters of different flock categories: as mortality in one flock category increases, the same pattern is observed with that of other categories. Mortality from disease and other unknown reasons is computed using the same procedure as predation mortality.

4. Bird off-take

Farmers try to maintain a bird flock at a certain target number, adjusted to household resources. Above certain a flock size, birds are consumed or sold. Consumption and sales vary with seasons and bird categories.

Bird sales: the number of birds sold depends on the number of birds left after mortality. No sales are allowed below minimum limits which depend on flock categories. Maximum limits are also set, beyond which all birds are sold. In addition, for flock sizes between the minimum and maximum limits the number of birds sold of category i in season j $\left(S_{ij}\right)$ is calculated using:

$$S_{ij} = AF_{ij} * \left(SR_{ij} + \left(R_j * SD_{ij}\right)\right) \qquad \text{(A1.05)}$$

where AF_{ij} is the number of birds present after mortality in category i in season j; SR_{ij} is the rate of sale (%) of category i in season j; SD_{ij} is the standard deviation of sale rate of category i in season j; and R_j is random coefficient of sale rate in season j.

Bird consumption: The number of birds consumed depends on the number of birds after mortality, and sale and the same minimum threshold limits as mentioned for bird sales. Given threshold limits, the number of consumed birds of category i in season j $\left(C_{ij}\right)$ is modeled as:

$$C_{ij} = SAF_{ij} * \left(CR_{ij} + \left(R_j * SD_{ij}\right)\right) \qquad \text{(A1.06)}$$

where SAF_{ij} is the number of birds present after sale of category i in season j, CR_{ij} is the consumption rate (%) of category i in season j; SD_{ij} is the standard deviation of consumption rate of category i in season j; and R_j is a random coefficient for consumption rate in season j.

The total weight of poultry meat consumed in season j $(TWBCj)$ was determined as a function of number, live weight and carcass percent of each flock category summed over i as follows:

$$TWBCj = \sum_{i} CC_{ij} * LW_{ij} * CP_{ij} \tag{A1.07}$$

where CC_{ij} is the number of birds consumed in category i in season j; LW_{ij} is the average live weight of category i in season j; and CP_{ij} is carcass percent of category i in season j.

The difference of the initial number of birds and the birds removed by mortality, sale and consumption was the net flock size and structure.

5. Egg production

Egg production depends on the average number of hens in the net flock in a specific season and the number of eggs laid in a clutch. The number of eggs per clutch is influenced by season because of differences in feed availability. The total number of eggs produced in season j $\left(EP_j\right)$ is computed as:

$$EP_j = 0.5*\left(H0_j + H1_j\right)*\left(P_j + \left(SD_j * R_j\right)\right) \tag{A1.08}$$

where $H0_j$ is the number of hens in the beginning of season j; $H1_j$ is the number of hens at the end of season j; P_j is the number of eggs per hen in season j; SD_j is the standard deviation of egg number per hen in season j; R_j is a random coefficient of the number of eggs per hen in season j. The model assumes that all hens become broody and have to spend some time incubating and rearing their chicks over a period of three months.

6. Reproduction

Setting eggs, incubation capacity of broody hens and hatchability determine the reproduction process. The model assumes that for the eggs produced, farmers' first priority is hatching to maintain the flock. The total number of eggs set for hatching and the hatchability rate determine the number of chicks born in one season. Number of incubated eggs in season j $\left(ES_j\right)$ is determined as:

$$ES_j = EP_j * \left(SR_j + \left(SD_j * R_j\right)\right) \qquad \text{(A1.09)}$$

where EP_j is the number of eggs produced in season j; SR_j is the rate of incubation in season j; SD_j is the standard deviation of SR_j; and R_j is a random coefficient of SD_j. The number of hatched eggs in season j $\left(EH_j\right)$ was calculated as:

$$EH_j = ES_j * \left(HR_j + \left(SD_j * R_j\right)\right) \qquad \text{(A1.10)}$$

where ES_j is the number of eggs incubated in season j; HR_j is the hatchability rate in season j; SD_j is the standard deviation of HR_j; and R_j a is random coefficient of SR_j.

7. Egg off-take

The egg off-take rate is defined as the number of eggs consumed or sold as a percentage of the total number of eggs produced. The egg off-take rate can fluctuate between seasons. The total number of eggs sold in season j $\left(SE_j\right)$ was calculated as:

$$SE_j = EP_j * \left(SER_j + \left(SD_j * R_j\right)\right) \tag{A1.11}$$

where EP_j is the number of eggs available (produced) in season j; SER_j is the egg sale rate in season j; SD_j is the standard deviation of EP_j; and R_j a is random coefficient of SD_j.

The number of eggs consumed in season j $\left(EC_j\right)$ is influenced by the number of eggs produced, incubated, lost or broken, and sold:

$$EC_j = EP_j - EB_j - ES_j - SE_j \tag{A1.12}$$

where EP_j is the number of eggs produced in season j; EB_j is the number of eggs broken or lost in season j; ES_j is the number of eggs incubated in season j; and SE_j is the number of eggs sold in season j.

Consumption can also be expressed in terms of egg mass in kg. Egg mass in season j $\left(EM_j\right)$ was calculated from the number of eggs consumed, and egg weight as indicated below:

$$EM_j = EC_j * \left(EW_j / 1000\right) \tag{A1.13}$$

where EC_j is the number of eggs consumed in season j; and EW_j is weight of eggs in grams in season j.

8. Average flock present

Flock size varies within a season due to mortality and off-take. Flock present refers to the average number of birds available in each season. The average number of birds is the average number of birds of category i in season j $\left(AvC_{ij}\right)$. This was computed as:

$$AvC_{ij} = \left(C0_{ij} + C1_{ij}\right)/2 \tag{A1.14}$$

where $C0_{ij}$ is the number of initial birds of category i in season j; and $C1_{ij}$ is the number of birds of category i left at the end of season j.

9. New flock

The flock size and structure change after each time step (season). The number of hens in a new season depends on the number of hens at the end of the previous season and the number of pullets becoming hens. The number of pullets joining hens depends on the age at first egg. The number of hens in the new flock in season $j+1$, NH_{j+1}, is calculated as:

$$NH_{j+1} = AFH_j + \left(AFP_j * \left(3/\left(age-3\right)\right)\right) \tag{A1.15}$$

where AFH_j is the number of hens at the end of season j; AFP_j is the number of pullets at the end of season j; and age is maturity age.

The number of cocks in the new flock is computed the same way as for hens. The number of cockerels joining the cocks depends on age of maturity. This age of maturity is assumed to be equal to the age at first egg for the pullets. All chicks in a new season come from chicks newly hatched in the previous season. After one season chicks are assumed to become growers and will be equally distributed as cockerels and pullets.

10. Manure Production

The model calculates the amount of dry matter in kg of dry matter (DM) manure produced in season j $\left(M_j\right)$ as a function of average birds present of different categories and their respective manure yield and dry matter:

$$M_j = \sum \left(CM_{ij} * AvC_{ij} \right) \tag{A1.16}$$

where CM_{ij} is the manure yield (kg of DM) of category i in season j; and AvC_{ij} is the average number of birds of category i in season j.

11. Workload

The workload expressed in total labor hours spent on poultry in season j $\left(LH_j\right)$ was determined considering time spent per day per bird and average flock size in a given season:

$$LH_j = \sum\left(\left(MCD_j * AvC_{ij}\right) * 90\right) \tag{A1.17}$$

where MCD_j is the average number of hours spent per day per bird in season j; and AvC_{ij} is the average present number of birds of category in season j.

12. Costs

The model separates costs of labor and other costs. The model has the ability to define input values of extra costs per day per bird of various inputs. It then calculates total cost of production in season j $\left(TC_j\right)$ as a result of input cost/day/bird, and average flock size in this season:

$$TC_j = \sum_i\left(BC_j * 90 * AvC_{ij}\right) \tag{A1.18}$$

where BC_j is the cost per bird per day in season j; and AvC_{ij} is the number of birds in category i in season j. Labor cost in season j $\left(LC_j\right)$ was calculated based on labor hours and labor costs per hour:

$$LC_j = \sum_i \left(LH_j * CLHR_j * AvC_{ij} * 90 \right) \quad \text{(A1.19)}$$

where LH_j is the number of hours spent per day per bird in season j; $CLHR_j$ is the cost of labor per hour in season j; and AvC_{ij} is the number of birds of category i in season j.

13. Benefits

The model considers benefits of cash income and opportunity values. The computations consider various bird categories and seasonal variations in flock size and prices.

Direct benefits include cash values of bird sales and consumptions, and egg sales and consumptions. The direct benefits in season j $\left(DB_j \right)$ are calculated as:

$$DB_j = \sum_i \left(\left(S_{ij} + C_{ij} \right) * BP_{ij} * R_j \right) + \left(\left(SE_j + EC_j \right) * EP_j * R_j \right) \quad \text{(A1.20)}$$

where S_{ij} is the number of birds sold in category i in season j; C_{ij} is the number of birds consumed in category i in season j; BP_{ij} is the price of birds in category i in season j; R_j is a random coefficient for prices in season j; SE_j is the number of eggs sold in season j; EC_j is number of eggs consumed in season j; and EP_j is the price of eggs in season j.

The indirect benefits in season j $\left(IB_j\right)$ are derived from the cash values of average present flock and manure production:

$$IB_j = \sum\left(AvC_{ij} * \left(AV/4\right) * BP_{ij} * R_j + \left(M_j * MP_j\right)\right) \tag{A1.21}$$

where AvC_{ij} is the average number of present birds in category i in season j; AV is the animal presence value, the value of having birds in case of urgent cash or social needs; BP_{ij} is the price of bird category i in season j; R_j is a random coefficient for prices in season j; M_j is the amount (kg DM) of poultry manure produced in season j; and MP_j is the price per kg of DM of manure in season j.

14. Net Return

Net return in season j $\left(NR_j\right)$ is calculated as the difference of the total benefits and total costs. This is done for every season according to the equation:

$$NR_j = \left(DB_j + IB_j\right) - TC_j \tag{A1.22}$$

where DB_j is direct benefits in season j; IB_j is indirect benefits in season j; and TC_j is the total cost in season j.

The model also calculates effectiveness of labor in terms of net return per labor hour:

$$LNR_j = \left(TB_j - TC_j\right) / \left(MCD * 90\right) \tag{A1.23}$$

where LNR_j is the net return per labor hour in season j; TB_j is the total benefits in season j; TC_j is the total cost in season j; and MCD is the number of labor hours per day.

Table A 2: Estimated Adoption Rates in Chibuto District

		Ceiling Level (%)								
Year		**15**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
1	1999	0.001	0.008	0.012	0.014	0.015	0.015	0.016	0.016	0.016
2	2000	0.004	0.013	0.018	0.020	0.021	0.022	0.022	0.022	0.022
3	2001	0.009	0.022	0.027	0.029	0.029	0.030	0.030	0.030	0.031
4	2002	0.023	0.035	0.039	0.040	0.041	0.041	0.041	0.041	0.042
5	2003	0.049	0.054	0.056	0.056	0.056	0.056	0.056	0.056	0.056
6	2004	0.085	0.079	0.077	0.077	0.076	0.076	0.076	0.076	0.076
7	2005	0.117	0.107	0.103	0.102	0.102	0.102	0.101	0.101	0.101
8	2006	0.136	0.133	0.133	0.134	0.134	0.134	0.134	0.134	0.134
9	2007	0.144	0.156	0.165	0.169	0.171	0.172	0.173	0.174	0.175
10	2008	0.148	0.172	0.195	0.206	0.213	0.217	0.220	0.222	0.224
11	2009	0.149	0.183	0.221	0.243	0.256	0.266	0.273	0.278	0.282
12	2010	0.150	0.190	0.243	0.277	0.300	0.317	0.330	0.340	0.348
13	2011	0.150	0.194	0.260	0.306	0.341	0.367	0.387	0.404	0.418
14	2012	0.150	0.197	0.273	0.331	0.376	0.413	0.443	0.469	0.490
15	2013	0.150	0.198	0.281	0.350	0.406	0.454	0.494	0.530	0.560
16	2014	0.150	0.199	0.287	0.364	0.430	0.488	0.539	0.584	0.625
17	2015	0.150	0.199	0.292	0.374	0.449	0.516	0.577	0.632	0.682
18	2016	0.150	0.200	0.294	0.382	0.463	0.538	0.607	0.671	0.731
19	2017	0.150	0.200	0.296	0.388	0.473	0.554	0.630	0.702	0.770
20	2018	0.150	0.200	0.298	0.391	0.481	0.567	0.649	0.727	0.802

Source: Author Computations

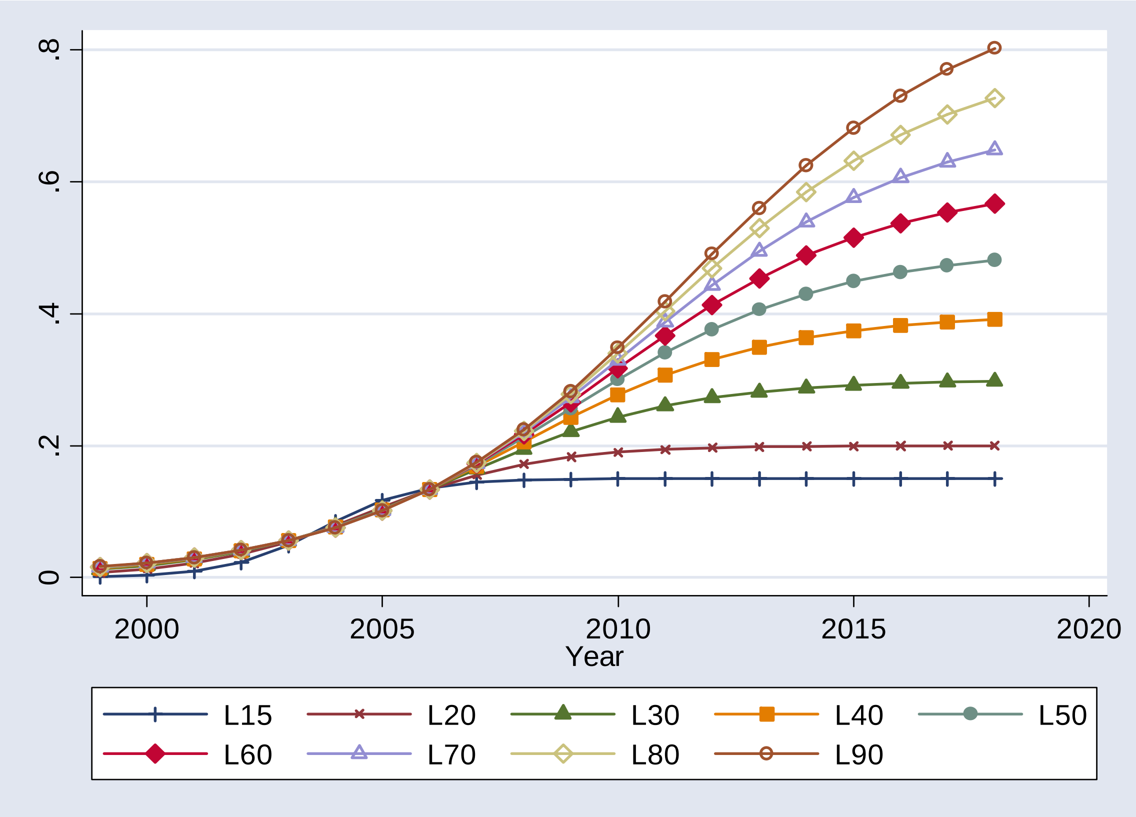

Figure A 1: I-2 Adoption Profiles at District Level Given the Adoption Ceiling Levels (Source: Author Computations)

Table A 3: Estimated Adoption Rates in the 44 Districts where I-2 Vaccine is Currently Used

		Ceiling Level (%)								
Year		10	20	30	40	50	60	70	80	90
1	1999	0.013	0.015	0.016	0.016	0.016	0.017	0.017	0.017	0.017
2	2000	0.016	0.018	0.019	0.019	0.019	0.019	0.019	0.019	0.020
3	2001	0.020	0.022	0.022	0.023	0.023	0.023	0.023	0.023	0.023
4	2002	0.025	0.026	0.026	0.027	0.027	0.027	0.027	0.027	0.027
5	2003	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
6	2004	0.037	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
7	2005	0.043	0.043	0.043	0.042	0.042	0.042	0.042	0.042	0.042
8	2006	0.050	0.050	0.050	0.049	0.049	0.049	0.049	0.049	0.049
9	2007	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
10	2008	0.064	0.066	0.066	0.066	0.066	0.067	0.067	0.067	0.067
11	2009	0.070	0.075	0.076	0.076	0.077	0.077	0.077	0.077	0.077
12	2010	0.075	0.084	0.086	0.088	0.088	0.089	0.089	0.089	0.089
13	2011	0.080	0.094	0.098	0.100	0.101	0.102	0.102	0.103	0.103
14	2012	0.084	0.103	0.110	0.113	0.115	0.117	0.117	0.118	0.119
15	2013	0.088	0.113	0.123	0.128	0.131	0.133	0.134	0.135	0.136
16	2014	0.090	0.123	0.136	0.143	0.148	0.151	0.153	0.155	0.156
17	2015	0.092	0.132	0.149	0.159	0.166	0.170	0.173	0.176	0.178
18	2016	0.094	0.140	0.163	0.176	0.185	0.191	0.195	0.199	0.202
19	2017	0.096	0.148	0.176	0.193	0.204	0.213	0.219	0.224	0.228
20	2018	0.097	0.155	0.189	0.210	0.225	0.236	0.244	0.251	0.256

Source: Author Computations

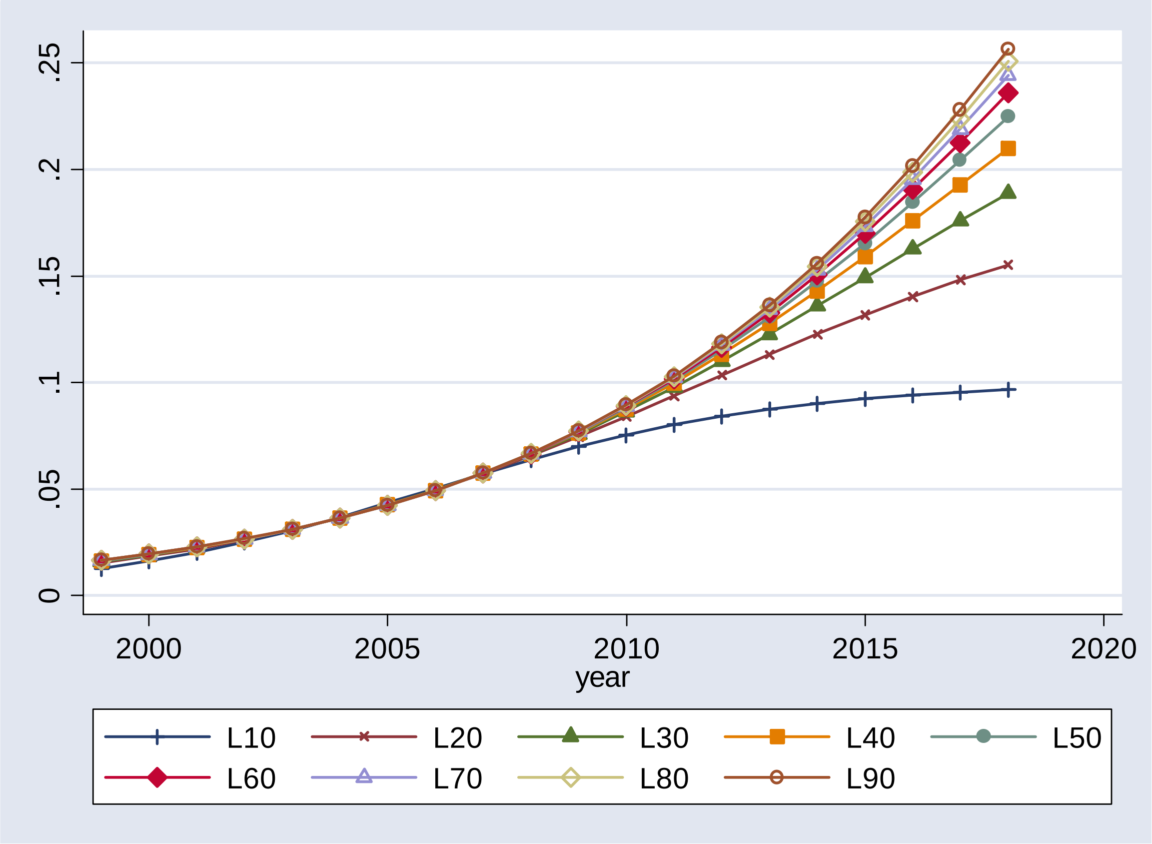

Figure A 2: I-2 Adoption Profiles in the 44 Districts Given the Adoption Ceiling Levels (Source: Author Computations)

Table A 4: Projected of Number of Total Households and Households Raising Chickens

Year	Number of Households		Households Raising Chickens	
	District	All Districts	District	All Districts
1997	28,130	1,367,404	19,114	954,756
1998	29,230	1,407,839	19,862	982,989
1999	30,374	1,449,470	20,639	1,012,056
2000	31,562	1,492,332	21,446	1,041,983
2001	32,796	1,536,461	22,285	1,072,796
2002	34,079	1,581,895	23,157	1,104,519
2003	35,412	1,628,673	24,063	1,137,180
2004	36,798	1,676,834	25,004	1,170,808
2005	38,237	1,726,419	25,982	1,205,429
2006	39,733	1,777,471	26,998	1,241,075
2007	41,287	1,830,032	28,055	1,277,774
2008	42,902	1,884,147	29,152	1,315,559
2009	44,580	1,939,863	30,292	1,354,461
2010	46,324	1,997,226	31,477	1,394,513
2011	48,136	2,056,285	32,708	1,435,750
2012	50,019	2,117,091	33,988	1,478,206
2013	51,976	2,179,695	35,317	1,521,918
2014	54,009	2,244,150	36,699	1,566,922
2015	56,121	2,310,511	38,134	1,613,257
2016	58,317	2,378,835	39,626	1,660,962
2017	60,598	2,449,179	41,176	1,710,078
2018	62,968	2,521,603	42,787	1,760,646

Source: Author Computations

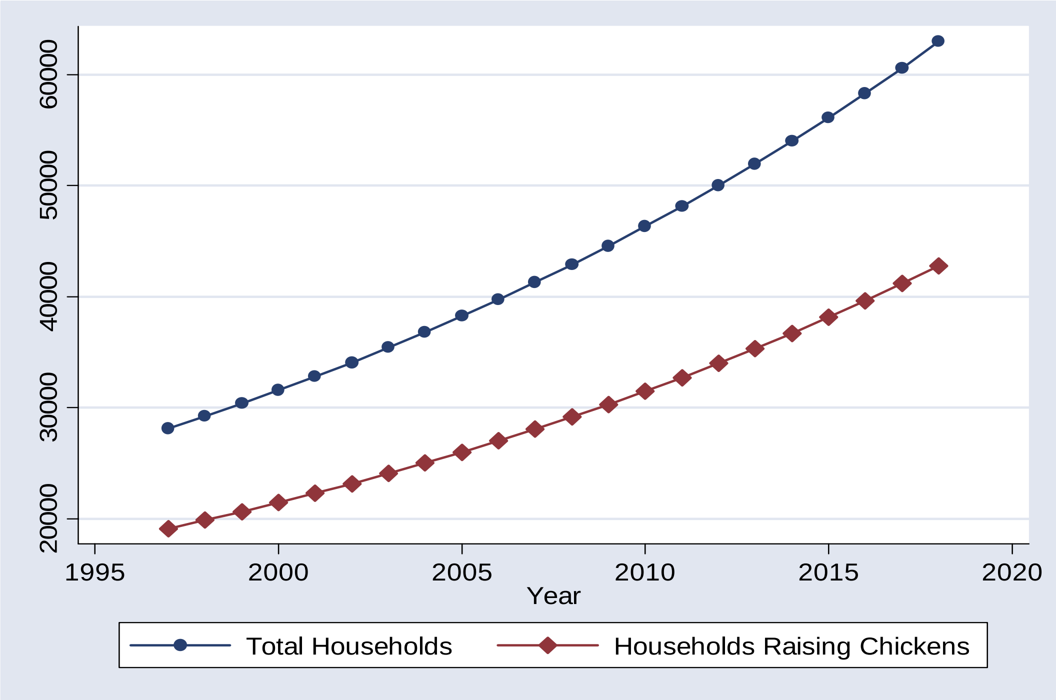

Figure A 3: Total Number of Households and Number of Households Raising Chickens at District Level (Source: Author Computations)

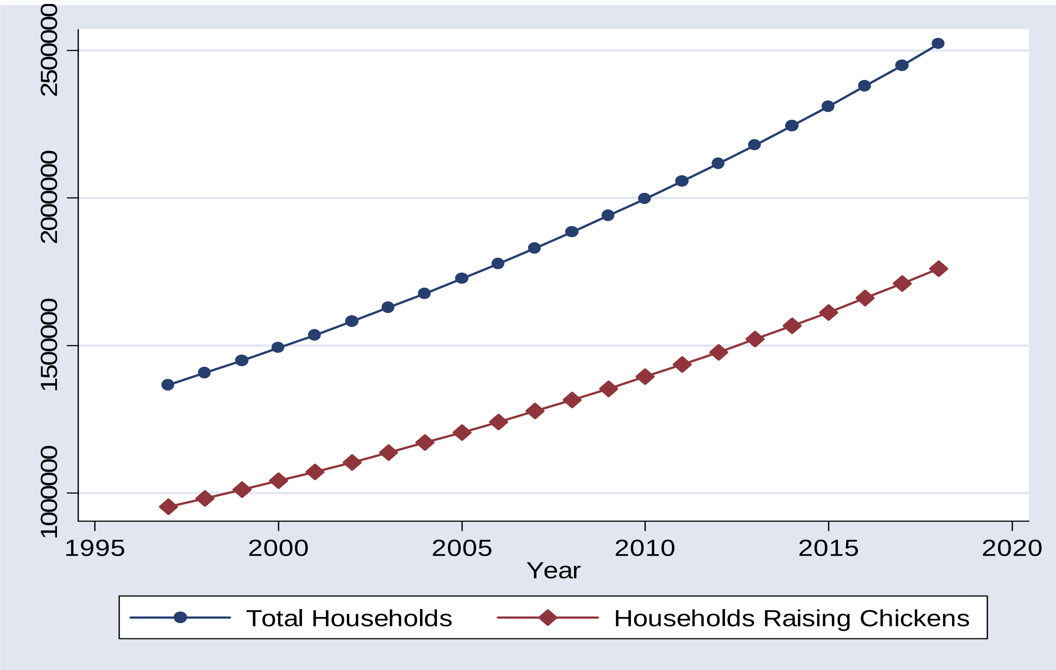

Figure A 4: Total Number of Households and Number of Households Raising Chickens in the 44 Districts (source: author computations)

Table A 5: Estimated Costs of Vaccination Program

Cost Description	Value (MTN)
1. Costs of Training, Materials & Other Investments at District Level	
Year 0	564,139
Year 1	593,234
Year 2*	441,434
*It is assumed that the value in year 2 is spent every 3 years for regular training	
2. Estimation of Annual Costs of Extension at District Level	**180,000**
2.1. Salary (Only a quarter is completely dedicated to the program in a year)	***126,000***
Non-Governamental Institution	384,000
Government Workers (two are need for full time working during a campaign)	120,000
2.2. Transport of vaccine from SSP (3 times a year)	***1,800***
Transport of Vaccine from SSP per Campaingn (about 20 liters of fuel)	600
2.3. Vaccine distribution during a campaign (3 times a year)	***7,200***
Vaccine Distribution & Monitoring during a campaign (about 80 liter of fuel)	2,400
2.4. Regular Assistance & Monitoring	***45,000***
3. Vaccine Production, Quality Control & Transporte to Province per Dose	**0.197**
3.1. Production & Quality Control	0.096
3.2. Distribution	0.101
To estimate the total cost in this category, cost per dose is multiplied by the number of doses produced each year	

Source: Author computations

Note: To get the costs in 1 and 2 at national level, the district costs are multiplied by 44.

Table A 6: Number of I-2 Doses Produced

Year	Number of Doses	Year	Number of Doses
1	1,460,500	11	7,500,000
2	916,250	12	8,049,045
3	1,124,000	13	8,598,091
4	955,250	14	9,147,136
5	1,422,750	15	9,696,182
6	1,939,750	16	10,245,227
7	2,244,250	17	10,794,273
8	1,896,750	18	11,343,318
9	2,445,795	19	11,892,364
10	2,994,841	20	12,441,409

Source: Author Computations

Table A 7: Farm Annual Net Benefits per Flock Category and ND Mortality Levels

Overall	Annual Net Benefits at 5% discount Rate (MTN)						
ND Mortality	**Cat 1**	**Cat 2**	**Cat 3**	**Cat 4**	**Cat 5**	**Cat 6**	**Overall**
5%	(41)	(50)	(59)	88	346	664	23
10%	(41)	(50)	95	188	413	907	66
15%	(41)	(1)	246	400	595	1,053	128
20%	(41)	67	288	580	647	1,062	165
25%	(41)	222	453	616	717	1,063	233
30%	(40)	306	503	670	712	1,108	268
35%	(71)	282	607	803	882	1,235	284
40%	77	342	639	790	808	1,162	361
45%	124	369	645	782	807	1,163	389
50%	149	392	633	778	794	1,164	404
55%	181	469	625	776	797	1,188	439
60%	242	481	610	760	794	1,187	466
63%	269	494	608	758	793	1,187	481
65%	261	490	608	755	794	1,188	477
70%	227	510	603	752	791	1,200	467
75%	285	494	596	749	789	1,214	488
80%	371	528	591	745	797	1,230	535
85%	415	546	589	757	810	1,245	562
90%	390	553	599	767	823	1,259	556
95%	498	569	605	773	829	1,264	610

Source: Author Computations

Table A 8: Profitability of the Vaccination Program at District Level

Year		Benefits	Extension costs	Others Costs	Net Benefits
0	1998			564,139	(564,139)
1	1999	148,070	180,000	593,234	(625,164)
2	2000	216,353	180,000	441,434	(405,082)
3	2001	314,530	180,000		134,530
4	2002	454,093	180,000		274,093
5	2003	649,450	180,000	441,434	28,016
6	2004	917,323	180,000		737,323
7	2005	1,274,894	180,000		1,094,894
8	2006	1,736,276	180,000	441,434	1,114,841
9	2007	2,307,600	180,000		2,127,600
10	2008	2,982,246	180,000		2,802,246
11	2009	3,738,811	180,000	441,434	3,117,376
12	2010	4,544,033	180,000		4,364,033
13	2011	5,360,299	180,000		5,180,299
14	2012	6,154,461	180,000	441,434	5,533,027
15	2013	6,903,989	180,000		6,723,989
16	2014	7,598,601	180,000		7,418,601
17	2015	8,238,217	180,000	441,434	7,616,783
18	2016	8,829,350	180,000		8,649,350
19	2017	9,381,671	180,000		9,201,671
20	2018	9,905,564	180,000		9,725,564
				NPV(MTN)*	**34,662,840**
				NPV(U$D)*	**$1,386,514**
				IRR	**37.39%**

Source: Author Computations

Note: The other costs are the costs of training, material and other investments. A discount rate of five percent is used for computation of NPV

Table A 9: Sensitivity Analysis of the Benefits of Vaccination to Overall Without-Control ND Mortality at the District Level

Year		**Net Benefits Per Level of Overall ND Mortality**				
		5%	**10%**	**15%**	**20%**	**25%**
0	1998	(564,139)	(564,139)	(564,139)	(564,139)	(564,139)
1	1999	(766,045)	(752,858)	(733,953)	(722,347)	(701,666)
2	2000	(610,930)	(591,662)	(564,038)	(547,080)	(516,862)
3	2001	(164,728)	(136,717)	(96,558)	(71,905)	(27,975)
4	2002	(157,952)	(117,512)	(59,533)	(23,941)	39,482
5	2003	(589,901)	(532,063)	(449,141)	(398,237)	(307,528)
6	2004	(135,461)	(53,767)	63,358	135,258	263,380
7	2005	(118,099)	(4,561)	158,219	258,145	436,209
8	2006	(537,132)	(382,505)	(160,815)	(24,725)	217,780
9	2007	(67,957)	137,550	432,187	613,058	935,359
10	2008	(35,201)	230,388	611,164	844,914	1,261,443
11	2009	(439,901)	(106,935)	370,440	663,490	1,185,688
12	2010	40,630	445,307	1,025,493	1,381,657	2,016,320
13	2011	80,263	557,634	1,242,042	1,662,185	2,410,856
14	2012	(322,612)	225,484	1,011,292	1,493,682	2,353,273
15	2013	155,215	770,061	1,651,569	2,192,708	3,156,985
16	2014	188,941	865,647	1,835,844	2,431,426	3,492,720
17	2015	(221,438)	512,231	1,564,094	2,209,810	3,360,438
18	2016	248,698	1,035,011	2,162,351	2,854,400	4,087,592
19	2017	275,515	1,111,016	2,308,877	3,044,218	4,354,551
20	2018	300,952	1,183,110	2,447,861	3,224,265	4,607,771
NPV(MTN)*		($3,160,822)	$379,528	$5,455,339	$8,571,268	$14,123,673
NPV(U$D)*		($126,433)	$15,181	$218,214	$342,851	$564,947
IRR		-	6.00%	15.03%	18.73%	23.95%

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 9 (Cont.): Sensitivity Analysis of the Benefits of Vaccination to Overall Without-Control ND Mortality at the District Level

		Net Benefits Per Level of Overall ND Mortality				
Year		**30%**	**35%**	**40%**	**45%**	**50%**
0	1998	(564,139)	(564,139)	(564,139)	(564,139)	(564,139)
1	1999	(690,784)	(685,853)	(662,241)	(653,621)	(649,028)
2	2000	(500,962)	(493,756)	(459,256)	(446,661)	(439,950)
3	2001	(4,860)	5,616	55,772	74,083	83,839
4	2002	72,853	87,978	160,389	186,825	200,910
5	2003	(259,800)	(238,169)	(134,606)	(96,797)	(76,652)
6	2004	330,794	361,347	507,626	561,030	589,485
7	2005	529,901	572,363	775,662	849,882	889,429
8	2006	345,378	403,208	680,079	781,160	835,018
9	2007	1,104,944	1,181,802	1,549,779	1,684,120	1,755,701
10	2008	1,480,608	1,579,936	2,055,493	2,229,111	2,321,619
11	2009	1,460,453	1,584,979	2,181,181	2,398,843	2,514,819
12	2010	2,350,260	2,501,606	3,226,210	3,490,750	3,631,704
13	2011	2,804,783	2,983,315	3,838,084	4,150,145	4,316,419
14	2012	2,805,562	3,010,546	3,991,954	4,350,248	4,541,157
15	2013	3,664,358	3,894,305	4,995,235	5,397,164	5,611,323
16	2014	4,051,139	4,304,221	5,515,916	5,958,284	6,193,989
17	2015	3,965,863	4,240,249	5,553,939	6,033,543	6,289,089
18	2016	4,736,459	5,030,533	6,438,487	6,952,505	7,226,387
19	2017	5,044,008	5,356,478	6,852,507	7,398,680	7,689,695
20	2018	5,335,729	5,665,648	7,245,218	7,821,890	8,129,156
NPV(MTN)*		17,045,175	18,369,234	24,708,501	27,022,851	28,255,998
NPV(U$D)*		681,807	734,769	988,340	1,080,914	1,130,240
IRR		26.27%	27.25%	31.55%	32.99%	33.73%

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 9 (Cont.): Sensitivity Analysis of the Benefits of Vaccination to Overall Without-Control ND Mortality at the District Level

Year		Net Benefits Per Level of Overall ND Mortality				
		55%	60%	62.90%	65%	70%
0	1998	(564,139)	(564,139)	(564,139)	(564,139)	(564,139)
1	1999	(638,048)	(629,733)	(625,164)	(626,563)	(629,534)
2	2000	(423,907)	(411,758)	(405,082)	(407,125)	(411,466)
3	2001	107,161	124,824	134,530	131,560	125,248
4	2002	234,581	260,082	274,093	269,805	260,694
5	2003	(28,495)	7,976	28,016	21,883	8,851
6	2004	657,504	709,018	737,323	728,661	710,254
7	2005	983,962	1,055,555	1,094,894	1,082,855	1,057,274
8	2006	963,763	1,061,266	1,114,841	1,098,446	1,063,606
9	2007	1,926,809	2,056,396	2,127,600	2,105,809	2,059,506
10	2008	2,542,751	2,710,224	2,802,246	2,774,084	2,714,243
11	2009	2,792,051	3,002,009	3,117,376	3,082,070	3,007,049
12	2010	3,968,643	4,223,820	4,364,033	4,321,123	4,229,945
13	2011	4,713,884	5,014,899	5,180,299	5,129,681	5,022,124
14	2012	4,997,509	5,343,121	5,533,027	5,474,909	5,351,417
15	2013	6,123,252	6,510,956	6,723,989	6,658,794	6,520,261
16	2014	6,757,424	7,184,134	7,418,601	7,346,846	7,194,376
17	2015	6,899,951	7,362,580	7,616,783	7,538,988	7,373,684
18	2016	7,881,082	8,376,906	8,649,350	8,565,973	8,388,807
19	2017	8,385,344	8,912,185	9,201,671	9,113,079	8,924,830
20	2018	8,863,651	9,419,913	9,725,564	9,632,025	9,433,264
NPV(MTN)*		**$31,203,738**	**$33,436,173**	**$34,662,840**	**$34,287,439**	**$33,489,755**
NPV(U$D)*		**$1,248,150**	**$1,337,447**	**$1,386,514**	**$1,371,498**	**$1,339,590**
IRR		**35.45%**	**36.71%**	**37.39%**	**37.18%**	**36.74%**

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 9 (Cont.): Sensitivity Analysis of the Benefits of Vaccination to Overall Without-Control ND Mortality at the District Level

Year		**Net Benefits Per Level of Overall ND Mortality**				
		75%	**80%**	**85%**	**90%**	**95%**
0	1998	(564,139)	(564,139)	(564,139)	(564,139)	(564,139)
1	1999	(623,072)	(608,523)	(600,433)	(602,204)	(585,713)
2	2000	(402,025)	(380,767)	(368,946)	(371,533)	(347,438)
3	2001	138,974	169,878	187,063	183,302	218,331
4	2002	280,510	325,127	349,937	344,507	395,079
5	2003	37,192	101,004	136,487	128,722	201,051
6	2004	750,285	840,417	890,536	879,567	981,730
7	2005	1,112,908	1,238,173	1,307,828	1,292,584	1,434,570
8	2006	1,139,375	1,309,972	1,404,836	1,384,075	1,577,445
9	2007	2,160,206	2,386,940	2,513,018	2,485,426	2,742,424
10	2008	2,844,384	3,137,405	3,300,343	3,264,684	3,596,818
11	2009	3,170,205	3,537,562	3,741,836	3,697,130	4,113,523
12	2010	4,428,240	4,874,713	5,122,982	5,068,648	5,574,719
13	2011	5,256,040	5,782,716	6,075,582	6,011,487	6,608,467
14	2012	5,619,988	6,224,695	6,560,951	6,487,360	7,172,786
15	2013	6,821,541	7,499,893	7,877,100	7,794,547	8,563,448
16	2014	7,525,968	8,272,568	8,687,727	8,596,868	9,443,128
17	2015	7,733,187	8,542,633	8,992,738	8,894,231	9,811,726
18	2016	8,774,107	9,641,634	10,124,036	10,018,461	11,001,790
19	2017	9,334,232	10,256,028	10,768,606	10,656,428	11,701,269
20	2018	9,865,528	10,838,799	11,380,001	11,261,558	12,364,745
NPV(MTN)*		**$35,224,556**	**$39,130,569**	**$41,302,567**	**$40,827,221**	**$45,254,628**
NPV(U$D)*		**$1,408,982**	**$1,565,223**	**$1,652,103**	**$1,633,089**	**$1,810,185**
IRR		**37.70%**	**39.78%**	**40.91%**	**40.66%**	**42.90%**

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 10: Sensitivity Analysis of the Benefits of Vaccination to Assumption of Adoption Ceiling Levels at District Level

Year		Net Benefits Per Ceiling Level of Adoption				
		15%	**20%**	**30%**	**40%**	**50%**
0	1998	(564,139)	(564,139)	(564,139)	(564,139)	(564,139)
1	1999	(759,682)	(697,408)	(651,832)	(634,351)	(625,164)
2	2000	(584,010)	(487,330)	(433,530)	(414,685)	(405,082)
3	2001	(79,197)	52,626	107,906	125,705	134,530
4	2002	75,475	211,345	254,803	267,800	274,093
5	2003	(52,684)	7,610	22,215	26,170	28,016
6	2004	844,893	770,578	747,807	740,781	737,323
7	2005	1,283,014	1,153,843	1,113,321	1,100,952	1,094,894
8	2006	1,143,208	1,111,353	1,111,504	1,113,472	1,114,841
9	2007	1,769,829	1,920,776	2,043,940	2,097,565	2,127,600
10	2008	1,894,806	2,232,718	2,553,232	2,709,541	2,802,246
11	2009	1,553,910	2,046,027	2,606,493	2,918,516	3,117,376
12	2010	2,087,991	2,696,912	3,504,948	4,014,183	4,364,033
13	2011	2,179,629	2,875,630	3,914,522	4,642,876	5,180,299
14	2012	1,831,623	2,594,386	3,836,398	4,786,207	5,533,027
15	2013	2,369,448	3,186,237	4,602,318	5,761,857	6,723,989
16	2014	2,469,341	3,332,698	4,897,556	6,247,908	7,418,601
17	2015	2,131,605	3,037,503	4,731,336	6,251,905	7,616,783
18	2016	2,680,754	3,627,326	5,435,749	7,107,632	8,649,350
19	2017	2,792,667	3,779,387	5,692,619	7,500,149	9,201,671
20	2018	2,908,952	3,936,125	5,948,019	7,879,141	9,725,564
NPV(MTN)*		**$13,423,804**	**$17,715,360**	**$24,492,751**	**$29,983,073**	**$34,662,840**
NPV(U$D)*		**$536,952**	**$708,614**	**$979,710**	**$1,199,323**	**$1,386,514**
IRR		**27.68%**	**31.46%**	**34.68%**	**36.33%**	**37.39%**

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 10 (Cont.): Sensitivity Analysis of the Benefits of Vaccination to Assumption of Adoption Ceiling Levels at District Level

Year		**Net Benefits Per Ceiling Level of Adoption**			
		60%	**70%**	**80%**	**90%**
0	1998	(564,139)	(564,139)	(564,139)	(564,139)
1	1999	(619,508)	(615,677)	(612,911)	(610,819)
2	2000	(399,260)	(395,355)	(392,553)	(390,444)
3	2001	139,805	143,315	145,818	147,695
4	2002	277,810	280,265	282,008	283,309
5	2003	29,083	29,779	30,269	30,632
6	2004	735,261	733,889	732,911	732,178
7	2005	1,091,291	1,088,899	1,087,195	1,085,920
8	2006	1,115,791	1,116,478	1,116,998	1,117,402
9	2007	2,146,808	2,160,149	2,169,957	2,177,470
10	2008	2,863,622	2,907,259	2,939,879	2,965,185
11	2009	3,255,187	3,356,319	3,433,698	3,494,811
12	2010	4,619,114	4,813,314	4,966,100	5,089,437
13	2011	5,592,885	5,919,522	6,184,506	6,403,772
14	2012	6,135,050	6,630,486	7,045,273	7,397,588
15	2013	7,534,167	8,225,440	8,822,072	9,342,195
16	2014	8,441,810	9,343,279	10,143,326	10,858,061
17	2015	8,846,862	9,960,539	10,973,324	11,898,203
18	2016	10,073,350	11,391,843	12,615,801	13,754,870
19	2017	10,803,839	12,314,221	13,740,092	15,088,151
20	2018	11,490,229	13,177,489	14,791,894	16,337,836
NPV(MTN)*		**$38,759,991**	**$42,409,491**	**$45,700,422**	**$48,695,702**
NPV(U$D)*		**$1,550,400**	**$1,696,380**	**$1,828,017**	**$1,947,828**
IRR		**38.16%**	**38.74%**	**39.21%**	**39.60%**

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 11: Profitability of the Vaccination Program in the 44 Districts of Implementation

Year		Benefits of Adoption	Extension Costs	Other Cost*	Production Cost	Distribution Cost	Net Benefits
0	1998			24,822,134			(24,822,134)
1	1999	8,000,981	7,920,000	26,102,314	140,208	147510.5	(26,309,051)
2	2000	9,680,923	7,920,000	19,423,114	87,960	92541.25	(17,842,692)
3	2001	11,701,395	7,920,000	-	107,904	113524	3,559,967
4	2002	14,126,379	7,920,000	-	91,704	96,480	6,018,195
5	2003	17,029,837	7,920,000	19,423,114	136,584	143,698	(10,593,558)
6	2004	20,496,451	7,920,000	-	186,216	195,915	12,194,320
7	2005	24,622,070	7,920,000	-	215,448	226,669	16,259,953
8	2006	29,513,705	7,920,000	19,423,114	182,088	191,572	1,796,932
9	2007	35,288,862	7,920,000	-	234,796	247,025	26,887,040
10	2008	42,073,993	7,920,000	-	287,505	302,479	33,564,010
11	2009	50,001,843	7,920,000	19,423,114	720,000	757,500	21,181,230
12	2010	59,207,474	7,920,000	-	772,708	812,954	49,701,812
13	2011	69,822,876	7,920,000	-	825,417	868,407	60,209,052
14	2012	81,970,181	7,920,000	19,423,114	878,125	923,861	52,825,082
15	2013	95,753,727	7,920,000	-	930,833	979,314	85,923,580
16	2014	111,251,483	7,920,000	-	983,542	1,034,768	101,313,174
17	2015	128,506,620	7,920,000	19,423,114	1,036,250	1,090,222	99,037,034
18	2016	147,520,239	7,920,000	-	1,088,959	1,145,675	137,365,605
19	2017	168,246,380	7,920,000	-	1,141,667	1,201,129	157,983,584
20	2018	190,590,314	7,920,000	-	1,194,375	1,256,582	180,219,356
						NPV(MTN)*	$410,616,275
						NPV(U$D)*	$16,424,651
						IRR	21.49%

Source: Author Computations

Note: The other costs are the costs of training, material and other investments. A discount rate of five percent is used for computation of NPV

Table A 12: Sensitivity Analysis of the Benefits of Vaccination to Overall Without-Control ND Mortality in the 44 Implementation Districts

	Net Benefits Per Level of Overall ND Mortality				
Year	**5%**	**10%**	**15%**	**20%**	**25%**
0 1998	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)
1 1999	(33,921,555)	(33,209,013)	(32,187,440)	(31,560,319)	(30,442,826)
2 2000	(27,053,570)	(26,191,418)	(24,955,349)	(24,196,553)	(22,844,423)
3 2001	(7,573,281)	(6,531,193)	(5,037,148)	(4,119,986)	(2,485,658)
4 2002	(7,422,296)	(6,164,246)	(4,360,577)	(3,253,343)	(1,280,318)
5 2003	(26,796,533)	(25,279,911)	(23,105,525)	(21,770,717)	(19,392,167)
6 2004	(7,306,951)	(5,481,604)	(2,864,598)	(1,258,074)	1,604,656
7 2005	(7,166,624)	(4,973,862)	(1,830,093)	99,799	3,538,753
8 2006	(26,283,773)	(23,655,378)	(19,887,040)	(17,573,739)	(13,451,573)
9 2007	(6,688,415)	(3,545,704)	960,011	3,725,972	8,654,752
10 2008	(6,467,134)	(2,720,160)	2,651,887	5,949,670	11,826,126
11 2009	(26,392,837)	(21,939,835)	(15,555,552)	(11,636,380)	(4,652,645)
12 2010	(6,630,918)	(1,358,092)	6,201,574	10,842,289	19,111,771
13 2011	(6,223,662)	(5,463)	8,909,588	14,382,344	24,134,474
14 2012	(25,165,140)	(17,865,142)	(7,399,112)	(974,243)	10,474,496
15 2013	(5,180,946)	3,346,571	15,572,497	23,077,727	36,451,608
16 2014	(4,536,634)	5,371,063	19,575,757	28,295,710	43,834,156
17 2015	(23,230,108)	(11,785,725)	4,622,121	14,694,542	32,643,005
18 2016	(2,991,974)	10,145,700	28,981,223	40,543,942	61,148,029
19 2017	(2,093,804)	12,889,673	34,371,529	47,558,774	71,057,673
20 2018	(1,117,085)	15,856,271	40,191,022	55,129,597	81,749,262
NPV(MTN	($204,261,077)	($146,707,658)	($64,193,151)	($13,539,287)	$76,722,932
NPV(U$D)	($8,170,443)	($5,868,306)	($2,567,726)	($541,571)	$3,068,917
IRR	-	-	0.00%	4.09%	9.30%

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 12 (Cont.): Sensitivity Analysis of the Benefits of Vaccination to Overall Without-Control ND Mortality in the 44 Implementation Districts

		Net Benefits Per Level of Overall ND Mortality				
Year		**30%**	**35%**	**40%**	**45%**	**50%**
0	1998	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)
1	1999	(29,854,835)	(29,588,351)	(28,312,491)	(27,846,698)	(27,598,512)
2	2000	(22,132,974)	(21,810,537)	(20,266,788)	(19,703,194)	(19,402,896)
3	2001	(1,625,725)	(1,235,993)	629,946	1,311,166	1,674,138
4	2002	(242,174)	228,326	2,480,959	3,303,354	3,741,548
5	2003	(18,140,648)	(17,573,445)	(14,857,818)	(13,866,392)	(13,338,134)
6	2004	3,110,936	3,793,599	7,062,023	8,255,265	8,891,056
7	2005	5,348,223	6,168,296	10,094,603	11,528,026	12,291,792
8	2006	(11,282,617)	(10,299,621)	(5,593,280)	(3,875,081)	(2,959,579)
9	2007	11,248,122	12,423,469	18,050,733	20,105,144	21,199,789
10	2008	14,918,135	16,319,469	23,028,711	25,478,132	26,783,249
11	2009	(978,020)	687,363	8,660,803	11,571,759	13,122,795
12	2010	23,462,915	25,434,905	34,876,301	38,323,182	40,159,772
13	2011	29,265,742	31,591,293	42,725,452	46,790,330	48,956,205
14	2012	16,498,466	19,228,601	32,299,805	37,071,862	39,614,541
15	2013	43,488,529	46,677,744	61,946,912	67,521,406	70,491,644
16	2014	52,010,003	55,715,393	73,455,879	79,932,605	83,383,577
17	2015	42,086,928	46,367,025	66,859,065	74,340,333	78,326,553
18	2016	71,989,259	76,902,632	100,426,639	109,014,823	113,590,836
19	2017	83,422,062	89,025,749	115,854,807	125,649,604	130,868,533
20	2018	95,755,702	102,103,586	132,495,673	143,591,266	149,503,295
NPV(MTN)		124,216,104	145,740,569	248,794,351	286,417,396	306,463,959
NPV(U$D)		4,968,644	5,829,623	9,951,774	11,456,696	12,258,558
IRR		11.49%	12.41%	16.31%	17.59%	18.25%

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 12 (Cont.): Sensitivity Analysis of the Benefits of Vaccination to Overall Without-Control ND Mortality in the 44 Implementation Districts

		Net Benefits Per Level of Overall ND Mortality				
Year		**55%**	**60%**	**62.90%**	**65%**	**70%**
0	1998	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)
1	1999	(27,005,241)	(26,555,934)	(26,309,051)	(26,384,606)	(26,545,150)
2	2000	(18,685,058)	(18,141,412)	(17,842,692)	(17,934,110)	(18,128,363)
3	2001	2,541,794	3,198,902	3,559,967	3,449,469	3,214,674
4	2002	4,789,016	5,582,304	6,018,195	5,884,798	5,601,344
5	2003	(12,075,375)	(11,119,040)	(10,593,558)	(10,754,373)	(11,096,086)
6	2004	10,410,863	11,561,871	12,194,320	12,000,770	11,589,497
7	2005	14,117,513	15,500,201	16,259,953	16,027,444	15,533,388
8	2006	(771,144)	886,241	1,796,932	1,518,230	926,021
9	2007	23,816,451	25,798,148	26,887,040	26,553,803	25,845,712
10	2008	29,903,026	32,265,752	33,564,010	33,166,700	32,322,461
11	2009	16,830,420	19,638,346	21,181,230	20,709,056	19,705,741
12	2010	44,549,993	47,874,874	49,701,812	49,142,709	47,954,677
13	2011	54,133,556	58,054,560	60,209,052	59,549,706	58,148,670
14	2012	45,692,612	50,295,766	52,825,082	52,051,027	50,406,249
15	2013	77,591,762	82,968,951	85,923,580	85,019,365	83,098,012
16	2014	91,632,850	97,880,338	101,313,174	100,262,612	98,030,288
17	2015	87,855,290	95,071,765	99,037,034	97,823,530	95,244,972
18	2016	124,529,429	132,813,641	137,365,605	135,972,553	133,012,475
19	2017	143,343,965	152,792,083	157,983,584	156,394,813	153,018,853
20	2018	163,635,525	174,338,398	180,219,356	178,419,588	174,595,285
NPV(MTN)		**$354,383,661**	**$390,675,067**	**$410,616,275**	**$404,513,606**	**$391,546,120**
NPV(U$D)		**$14,175,346**	**$15,627,003**	**$16,424,651**	**$16,180,544**	**$15,661,845**
IRR		**19.78%**	**20.89%**	**21.49%**	**21.31%**	**20.92%**

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 12 (Cont.): Sensitivity Analysis of the Benefits of Vaccination to Overall Without-Control ND Mortality in the 44 Implementation Districts

		Net Benefits Per Level of Overall ND Mortality				
Year		75%	80%	85%	90%	95%
0	1998	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)
1	1999	(26,195,999)	(25,409,863)	(24,972,720)	(25,068,390)	(24,177,316)
2	2000	(17,705,902)	(16,754,704)	(16,225,775)	(16,341,532)	(15,263,363)
3	2001	3,725,306	4,875,026	5,514,345	5,374,429	6,677,619
4	2002	6,217,798	7,605,785	8,377,596	8,208,684	9,781,945
5	2003	(10,352,929)	(8,679,663)	(7,749,218)	(7,952,848)	(6,056,227)
6	2004	12,483,932	14,497,810	15,617,657	15,372,576	17,655,276
7	2005	16,607,859	19,027,099	20,372,354	20,077,943	22,820,115
8	2006	2,213,956	5,113,824	6,726,339	6,373,437	9,660,392
9	2007	27,385,666	30,852,972	32,781,019	32,359,062	36,289,200
10	2008	34,158,509	38,292,487	40,591,248	40,088,160	44,773,961
11	2009	21,887,748	26,800,677	29,532,585	28,934,701	34,503,431
12	2010	50,538,404	56,355,832	59,590,701	58,882,743	65,476,709
13	2011	61,195,638	68,056,082	71,870,936	71,036,047	78,812,255
14	2012	53,983,308	62,037,284	66,515,820	65,535,683	74,664,742
15	2013	87,276,565	96,684,843	101,916,458	100,771,509	111,435,648
16	2014	102,885,139	113,816,149	119,894,503	118,564,242	130,954,374
17	2015	100,852,813	113,479,225	120,500,333	118,963,748	133,275,594
18	2016	139,450,043	153,944,638	162,004,576	160,240,642	176,670,043
19	2017	160,360,879	176,891,920	186,084,255	184,072,494	202,810,176
20	2018	182,912,367	201,638,810	212,051,932	209,772,999	230,999,135
NPV(MTN)*		**$419,747,763**	**$483,245,568**	**$518,554,482**	**$510,827,052**	**$582,800,842**
NPV(U$D)*		**$16,789,911**	**$19,329,823**	**$20,742,179**	**$20,433,082**	**$23,312,034**
IRR		**21.76%**	**23.60%**	**24.59%**	**24.37%**	**26.36%**

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 13: Sensitivity Analysis of the Benefits of Vaccination to Assumption of Adoption Ceiling Level in the 44 Implementation Districts

Year		Net Benefits Per Ceiling Level of Adoption				
		10%	**20%**	**30%**	**40%**	**50%**
0	1998	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)
1	1999	(28,115,910)	(26,787,841)	(26,502,754)	(26,378,570)	(26,309,051)
2	2000	(19,437,812)	(18,255,695)	(18,009,079)	(17,902,304)	(17,842,692)
3	2001	2,304,542	3,240,520	3,431,664	3,514,056	3,559,967
4	2002	5,220,541	5,817,290	5,937,640	5,989,387	6,018,195
5	2003	(10,859,875)	(10,660,521)	(10,620,403)	(10,603,162)	(10,593,558)
6	2004	12,440,545	12,256,737	12,219,392	12,203,285	12,194,320
7	2005	16,850,780	16,412,440	16,321,426	16,281,977	16,259,953
8	2006	2,358,299	1,945,648	1,857,208	1,818,577	1,796,932
9	2007	26,792,773	26,858,773	26,875,269	26,882,753	26,887,040
10	2008	31,910,579	33,077,057	33,361,881	33,490,621	33,564,010
11	2009	16,787,807	19,813,912	20,605,862	20,971,038	21,181,230
12	2010	41,133,621	46,861,772	48,486,409	49,254,323	49,701,812
13	2011	45,817,331	55,107,509	57,982,717	59,381,673	60,209,052
14	2012	30,795,859	44,460,770	49,093,952	51,423,417	52,825,082
15	2013	54,329,298	73,080,734	80,056,136	83,692,339	85,923,580
16	2014	58,164,161	82,576,653	92,532,930	97,929,033	101,313,174
17	2015	42,332,111	72,825,557	86,425,596	94,105,001	99,037,034
18	2016	65,142,050	101,981,543	119,878,189	130,420,379	137,365,605
19	2017	68,366,306	111,675,295	134,477,483	148,497,011	157,983,584
20	2018	71,468,058	121,250,216	149,493,845	167,614,320	180,219,356
NPV(MTN)*		**$213,141,867**	**$318,469,082**	**$365,480,256**	**$392,729,343**	**$410,616,275**
NPV(U$D)*		**$8,525,675**	**$12,738,763**	**$14,619,210**	**$15,709,174**	**$16,424,651**
IRR		**17.36%**	**19.96%**	**20.80%**	**21.23%**	**21.49%**

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

Table A 13 (Cont.): Sensitivity Analysis of the Benefits of Vaccination to Assumption of Adoption Ceiling Level in the 44 Implementation Districts

Year		Net Benefits Per Ceiling Level of Adoption			
		60%	**70%**	**80%**	**90%**
0	1998	(24,822,134)	(24,822,134)	(24,822,134)	(24,822,134)
1	1999	(26,264,625)	(26,233,774)	(26,211,107)	(26,193,747)
2	2000	(17,804,658)	(17,778,271)	(17,758,898)	(17,744,070)
3	2001	3,589,224	3,609,509	3,624,394	3,635,781
4	2002	6,036,538	6,049,253	6,058,582	6,065,713
5	2003	(10,587,449)	(10,583,211)	(10,580,099)	(10,577,729)
6	2004	12,188,596	12,184,633	12,181,729	12,179,491
7	2005	16,245,883	16,236,123	16,228,965	16,223,462
8	2006	1,783,075	1,773,447	1,766,383	1,760,941
9	2007	26,889,807	26,891,738	26,893,189	26,894,262
10	2008	33,611,422	33,644,568	33,669,083	33,687,875
11	2009	21,317,828	21,413,709	21,484,773	21,539,451
12	2010	49,994,811	50,201,520	50,355,242	50,473,904
13	2011	60,755,727	61,143,787	61,433,620	61,658,159
14	2012	53,761,168	54,430,541	54,933,104	55,324,084
15	2013	87,432,223	88,520,270	89,342,249	89,984,846
16	2014	103,633,622	105,323,613	106,609,544	107,620,507
17	2015	102,471,990	105,001,443	106,941,969	108,477,371
18	2016	142,285,881	145,953,763	148,793,678	151,057,017
19	2017	164,828,702	170,000,251	174,045,386	177,295,336
20	2018	189,492,897	196,600,789	202,222,576	206,779,435
NPV(MTN)*		**$423,286,987**	**$432,742,522**	**$440,074,046**	**$445,925,285**
NPV(U$D)*		**$16,931,479**	**$17,309,701**	**$17,602,962**	**$17,837,011**
IRR		**21.66%**	**21.79%**	**21.89%**	**21.96%**

Source: Author Computations

Note: A discount rate of five percent is used for computation of NPV

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