Bioeconomic Modelling of Foot and Mouth Disease and Its Control in Ethiopia

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Preface

It all started six years ago when I met Nico Wageningen in Dire Dawa, Ethiopia during his mission of coordinating a Nuffic (Netherlands Organization for International Cooperation in Higher Education) project supporting veterinary schools in Ethiopia. During a chat at coffee break of a meeting, I told Nico about my keen interest to do a PhD in animal health economics, which I had been thinking that it would be an essential complement to my veterinary epidemiology background for a productive career in supporting animal health management decisions. In our later communications, Nico suggested me the right place and person for my ambition: Business economic Group and Prof. Henk Hogeveen at Wageningen University. When I contacted Henk about my interest, he took no time to accept me as his student. This initiated the PhD project. With a generous support from Business Economics Group, I won Nuffic fellowship for the project. The result of this project is what is documented in this thesis. At this moment, I would like to thank Nuffic for the valuable financial support. I sincerely thank Nico Wageningen for helping me realizing my ambition. I very much thank Henk for having confidence on me and giving the chance to do PhD under his supervision. I would also like to thank Prof. Alfonse Oude Lansink, chair of Business Economics Group, for allowing and facilitating my PhD study in his group.

I owe great intellectual debt to my supervisory team at Business Economics Group of Wageningen University: Prof. Henk Hogeveen, Dr. Monique Mourits and Prof. Alfonse Oude Lansink. I thank you all for your unreserved and tireless mentoring and guidance through the regular meetings, paper reviews and informal discussions I had with you throughout my PhD study. Henk, your constant encouragement and deliberate appreciation even when things were not at their best was a great motivation for more effort in my work. I really cherished your considerate supervision. Monique, your commitment and diligence to guide and support my effort has been the most important element for this accomplishment. I very much appreciate your devotion to repeatedly review my papers until they get right. I learn a lot from your critical and meticulous scrutiny of the scientific reports I was writing. I really thank you very much. My thanks also go to my local supervisor Dr Tassew W/Hana from Addis Ababa University for his generous assistance during the application and execution of my PhD project.

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I would like to seize this moment to thank Professor Jonathan Rushton and his group at Royal Veterinary College, University of London who hosted me for a research visit during my PhD tenure. I very much appreciate your warm hospitality and useful coaching during my stay at your group in Royal Veterinary College. It was a very useful and interesting experience to be at your group.

I would like to acknowledge the staff of the secretariat of Business Economics Group: Anne Houwers, Jeanette Lubbers-Poortvliet, and Ilona van den Berg for easing all essential administrative issues. I enjoyed your most welcome for any administrative issues I had in your office. Thank you so much for your kindness and support. I would also like to thank all PhD colleagues and staff at Business Economics Group who made my stay in the group pleasant and unforgettable.

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Abstract

Foot and mouth disease (FMD) is a highly contagious viral disease which affects cloven hoofed animals. FMD is endemic in Ethiopia with potential impact both on national and household economies because of its effect on production and trade. The general objective of this PhD research was to provide insight into the epidemiology and economics of FMD and its control in Ethiopia to support decision making in the control of the disease.

A study of the national incidence of FMD outbreak revealed that the disease is endemic in all regional states affecting more than a quarter of the country every year, with the highest frequency of outbreaks occurring in the central, southern and southeastern parts of the country. The type of production system, presence of a major livestock market and/or route, and adjacency to a national parks or wildlife sanctuary were associated with the risk of outbreaks in the districts.

Field outbreak study indicated that FMD morbidity rates of 85% and 95 % at herd level; and 74% and 61% at animal level in the affected herds in the crop–livestock mixed system (CLM) and pastoral system, respectively. The herd level economic loss estimates were on average USD 76 per affected herd in CLM and USD 174 per affected herd in the pastoral production system.

Study of motivation of farmers to implement FMD control, through the Health Belief Model (HBM) framework, revealed that almost all farmers had high intention to implement FMD vaccination free of charge, which decreases, especially in CLM system, if the vaccine is charged. Farmers in the pastoral and crop-livestock mixed production systems had low intention to implement herd isolation and animal movement restriction control measure. Among the HBM perception constructs perceived barrier was found to be the most important predictor of the intention to implement FMD control measures.

A modelling study on the national economic impact and cost-benefit analysis FMD control strategies showed that the annual cost of the disease is about 1,354 million birr. A stochastic cost-benefit analysis of three potential FMD control strategies indicated that all the strategies on average have a positive economic return but with variable degree of uncertainty including possibility of loss. Targeted vaccination strategy gives relatively the best economic return with relatively less risk of loss.

Keywords: Control, cost-benefit, economic impact, epidemiology, Ethiopia, Foot and mouth disease, intention, modelling, production system.

Chapter 1

General Introduction

1.1 Background

1.1.1 Livestock production in Ethiopia

Agriculture represents the backbone of the Ethiopian economy by contributing up to 45% to the total GDP and by employing about 78 % of the workforce in the country (Martins, 2014). Low input-output smallholder subsistence farming dominates the agricultural sector and produces about 90% of the total agricultural output (MoARD, 2007a). The livestock sub-sector is an important integral part of the subsistence agriculture. As such, livestock provides draft power (up to 80% of the total agricultural power needs) and manure fertilizer for crop production and in turn utilizes the crop residues as feed. The Ethiopian livestock contribution to the national economy is estimated at 19% of the total GDP, 45% of the agricultural GDP, and about 20% of the country's export earnings (Behnke and Metaferia, 2011).

The livestock production in Ethiopia can be broadly classified into three systems. The dominant production system is the crop-livestock mixed (CLM) system that is mainly found in the central highland parts of the country (Figure 1.1). This system accounts for about 80 - 85% of the cattle population and 40% of the land area of the country (MoARD, 2007a). The functions of livestock in this system include draft power for crop production, manure for fertilizer and cooking fuel, meat and milk for the household consumption, and household earning up to 85% of the total farm income (Otte and Chilonda, 2002; Tegegne et al., 2010). The second most dominant farming system is the pastoral production system, which is practiced in the arid and semiarid peripheral parts of the country (Figure 1.1), and accounts for about 15-20% of the cattle population and 60 % of the land area of the country (MoARD, 2007a). The function of livestock in this system is to provide farm cash income, food (milk and meat) for subsistence, and other social functions such as social prestige, dowry, ritual slaughter etc. (Otte and Chilonda, 2002). Ninety five percent of the export of animal and animal products in Ethiopia is sourced from this system (Legese et al., 2008).The third type of production system is the small but growing market oriented production in urban and peri-urban parts of the country. This system primarily consists of dairy farms keeping improved breeds and to some extent feedlots, and accounts for less than 1% of the total cattle population.

Cattle are the dominant livestock species in Ethiopia, representing about 71% of the livestock biomass (MoARD, 2007b) and producing 72% of the domestic meat and 77% of the domestic milk (MoA, 2014). The latest estimate of the cattle population size in the sedentary and some pastoral rural areas of Ethiopia is approximately 54 million (CSA, 2013). When accounting for the remaining pastorals zones[1] and urban areas that are not covered by the annual central statistical agency (CSA) surveys, the

1 Adjusted based on proportion the Afar and Somali cattle population estimated in MoRAD, 2007.

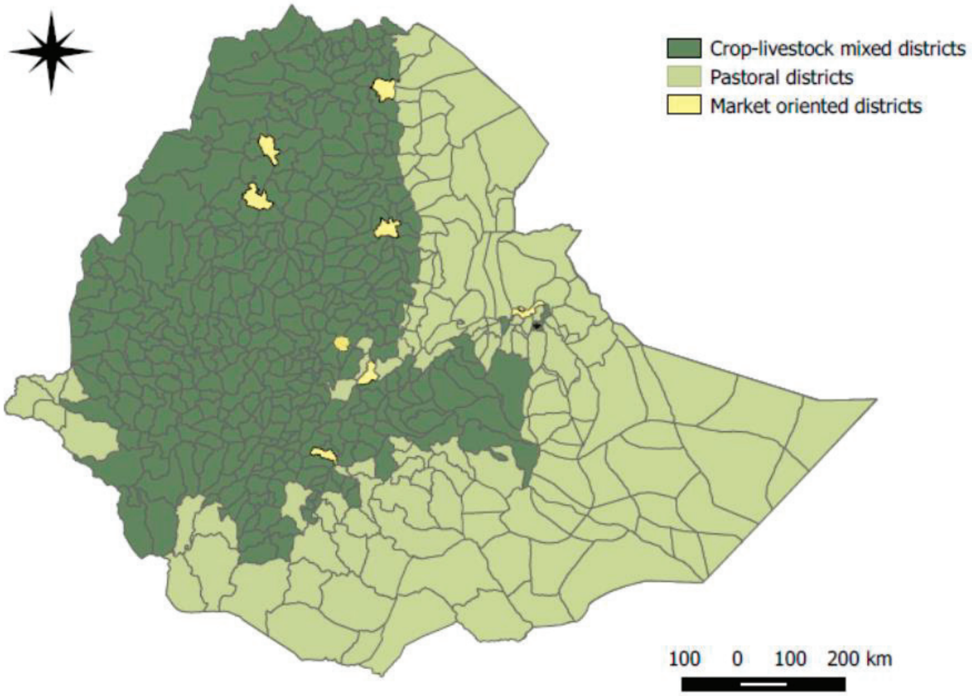

Figure 1.1. Map of Ethiopia showing the geographic distribution of livestock production systems.

cattle population size is estimated to be about 57 million. This makes the Ethiopian cattle population the largest in Africa and the fifth largest in the world (FAO, 2013).

Despite Ethiopia's huge cattle population, the benefits derived from it are low due to poor production and productivity. The average national meat yield of 107.3 kg dressed carcass weight and milk yield of 352 kg per cow per year are low compared with the world average of, respectively, 214 kg dressed cattle carcass weight and 2 318 kg of milk yield per cow per year (FAO, 2013). Consequently, the average per capita annual consumption of meat and dairy products in Ethiopia, which are about 4.6 kg and 16.7 kg, respectively (Tafere and Worku, 2012), are also low compared with corresponding world averages of, respectively, 36 kg and 78 kg (Bruinsma, 2003).

The low performance of the livestock sector is due to a host of policy and technical constraints. Livestock diseases are among the important technical constraints that have hindered the development of the sector by decreasing production and hampering trade in animal and animal products. Foot and mouth disease (FMD) is considered one of the livestock diseases of major socio-economic importance in Ethiopia.

1.1.2 Foot and Mouth disease in Ethiopia

FMD is a highly contagious trans-boundary disease that affects all cloven hoofed animals. It is caused by a virus that belongs to the genus *Aphthovirus* of the family *Picornaviridae* (Mahy, 2005). Foot and mouth disease virus (FMDV) occurs in seven distinct serotypes: A, O, C, and South African Territories (SAT) 1, SAT 2, SAT 3 and Asia 1. Within each serotype, many subtypes can be identified by genetic and immunological tests (OIE, 2012). More than 60 subtypes (topotypes or genotype groups) have been described within the seven serotypes of FMD virus. The different serotypes do not cross protect each other and different subtypes within serotypes may not also cross protect, depending on their genetic closeness (Mahy, 2005). The virus affects an extensive range of hosts including domestic ruminants and pigs, and more than 70 wildlife species (Mahy, 2005). Cattle are the primary maintenance hosts for FMD viruses other than SAT viruses, although in some instances some virus strains appear to be specifically adapted to other livestock species like Cathay topotype of O in pigs (OIE, 2012). African buffalo (*Syncercus cafer*) is the natural maintenance host for SAT viruses. FMD is clinically obvious and its effect is more pronounced on cattle and pigs but often unapparent and mild in small ruminants (Kitching and Alexandersen, 2002; Kitching and Hughes, 2002; Kitching, 2002).

FMD is endemic in Ethiopia since it was diagnosed for the first time in 1957 (Martel and Gallon, 1975 cited in Ayelet *et al,* 2009). A large number of outbreaks are reported every year (Ayelet et al., 2012). The FMD outbreak occurrence in the country is apparently increasing since the 1990's (Asfaw and Sintaro, 2000). Several sero-surveys conducted in various parts of the country reported sero-prevalences that range from 9% to 26% at animal level and up to 48 % at herd level in cattle (Bayissa et al., 2011; Megersa et al., 2009; Mekonen et al., 2011; Mohamoud et al., 2011; Negusssie et al., 2010; Rufael et al., 2007).

Among the seven serotypes of FMD viruses, five of them (O, A, C, SAT1 and SAT2) have been diagnosed in Ethiopia at different times (Ayelet et al., 2009; Gelaye, 2005; Negusssie et al., 2010). The most dominant serotype is O, accounting for 72% of the investigated outbreaks occurring in the country, followed by A (19.5%) (Ayelet et al., 2009). Serotype C has not been reported in Ethiopia since 1983 (Ayelet et al., 2009). Seven topotypes are identified within the four serotpyes of FMD viruses that have been reported in recent times in Ethiopia. These topotypes include EA-3 and EA-4 within serotype O; G-VII (Africa topotype) within serotype A; IV, XIII and XIV within serotype SAT 2; and IX within serotype SAT 1 (Ayelet et al., 2009).

There has never been any official control plan against FMD in Ethiopia except vaccination in some market oriented dairy farms in urban and peri-urban areas. The vaccination is either reactive vaccination in response to outbreaks or regular preventive vaccination (Beyi, 2012). FMD infected cattle are commonly treated with palliative antibiotics or traditional treatments in all types of production systems.

1.1.3 Economic importance of FMD

FMD is considered as the most important livestock disease in the world in terms of economic impact (James and Rushton, 2002). The annual economic impact of FMD in terms of visible production losses and vaccination costs in endemic regions of the world is estimated between US$6.5 and 21 billion, whereas outbreaks in FMD free countries and zones cause losses of more than US$1.5 billion a year (Knight-Jones and Rushton, 2013). Losses in endemic situations consist of both direct and indirect effects. The direct effects of the disease are loss of milk production, loss of meat production, loss of draft power, poor growth, abortion in pregnant animals and death, especially in young animals. The indirect losses are attributed to the disruption in trade of animals and animal products, use of suboptimal technology in livestock farming because of fear of the disease and costs to improve the disease status for international trade (Rushton, 2009). When the disease occurs in FMD free countries, there are costs to eradicate the disease as well as additional consequential costs such as idle production capacity in case of pre-emptive slaughter and welfare culling in combination with movement restrictions (Saatkamp et al., 2014). During such disease incursions, the impact of the disease could also spill over to other sectors of the economy. For example, in the UK, the rural tourism sector suffered between £2.7 and £3.2 billion as result of movement restrictions during the 2001 FMD outbreak (Thompson et al., 2002).

The direct economic impact of FMD at farm level is very important in intensive dairy and pig systems. The impact of the disease to the indigenous animals kept under traditional extensive system is considered relatively low (James and Rushton, 2002; Perry et al., 2003). Generally the economic impact of the disease and the incentive to invest in a national control program depend mainly on the type of farming system and the exporting potential of the country for animal and animal products (James and Rushton, 2002; Randolph et al., 2002). Returns on investment of FMD control are highest in countries where there is a developed livestock farming systems or a large potential for international trade in livestock and livestock products.

1.2 Problem statement

FMD is endemic in Ethiopia with several outbreak reports every year (Ayelet et al., 2012). A participatory appraisal study on Borena pastoralists in southern Ethiopia indicated that FMD has become the number one livestock disease problem after the control and eventual eradication of rinderpest in the past couple of decades (Jibat et al., 2013). Similar types of studies in other parts of Ethiopia ranked FMD as the economically most important viral disease, and among the top five important diseases of cattle (Admassu, 2004; Shiferaw et al., 2010). Moreover, the growing trend of private investments in the livestock sector and the increased export of live animals and meat in the past decade, coupled with growing international concerns on the zoo-sanitary importance of FMD prompted more attention to the disease. There has never been an official control plan against the disease in Ethiopia except some vaccination on commercial dairy farms in urban and peri-urban areas that keep cross-bred animals. There is, however, an increasing interest to launch a national control program against FMD to mitigate the impact of the disease on production and international trade (MoARD, 2006; Thomson, 2014).

Designing an appropriate disease control policy requires a sound knowledge of the epidemiology and economics of the disease. For FMD, epidemiological information about the prevailing virus types, factors associated with its spread, and geographic regions and husbandry systems at higher risk of the disease is an important input for defining effective control strategy. Moreover, the control of FMD should be economically viable under the existing or expected livestock production systems and trade scenarios. Successful livestock disease control programs depend not only on technical and economic feasibilities but also on the motivation of the stakeholders, especially the farming community, to fully participate in the implementation of the control programs (Roeder and Taylor, 2007). Knowledge of farmers perceptions about the disease and their motivation to apply control measures is, therefore, important in designing effective disease control programs.

Because of the high transmissibility and transboundary nature of FMD and associated externalities involved in its control, FMD control is considered as a public good and requires control at national level. Although several serological and outbreak related studies have been carried out in different parts of Ethiopia (Bayissa et al., 2011; Megersa et al., 2009; Mekonen et al., 2011; Mohamoud et al., 2011; Negusssie et al., 2010; Rufael et al., 2007), epidemiological information at the national level that can serve as a basis for assessing the economic impact of the disease and defining a relevant control program at the national level is lacking. Besides a good epidemiological intelligence, a sound economic appraisal of the impact of the disease and its control is vital to support the control decision making. This is particularly important for the situation in Ethiopia, where positive returns on investment in FMD control might not be guaranteed because of the dominant subsistence oriented cattle production. Only few localized outbreak based studies made a cost estimate for FMD in Ethiopia. Results from these studies indicate the economic importance of the disease (Bayissa et al., 2011; Mazengia et al., 2010; Mersie et al., 1992). However, a national estimate of the economic costs of FMD and an evaluation of the economic returns from potential control intervention are lacking.

This study endeavors to fill these gaps by generating a national level epidemiologic and economic information on FMD and its control in cattle production of Ethiopia.

1.3 Objectives

The overall objective of the study described in this thesis was to generate information on the epidemiology and economics of FMD and its control that can be used to support decision making in the control of FMD in Ethiopia. The specific objectives were to:

1. Determine the national incidence, geographical and temporal distribution, risk factors and causal serotypes of FMD outbreaks;
2. Assess the farm level clinical and economic impact of FMD outbreaks;
3. Assess farmers' intentions to implement FMD control measures, and identify perceptions about the disease and its control measures that influence the intentions to implement the control measures;
4. Explore the transmission dynamics of FMD outbreaks in different production systems by mathematical modelling; and
5. Estimate the total national costs of FMD, and analyze the costs and benefits of potential control options in Ethiopia.

1.4 Thesis outline

This thesis is organized into seven chapters, including this general introduction (Chapter 1) and a general discussion (Chapter 7). Chapters 2 to 6 address each of the specific objectives of the study. Figure 1.2 provides a schematic overview of the structure of the thesis along with its information flow.

Chapter 2 deals with the national epidemiology of the disease. In this chapter, the national incidence of FMD outbreaks is estimated, the geographic distribution mapped, the temporal pattern analyzed, risk factors modeled, and the serotypes of outbreaks identified. Chapter 3 assesses the clinical and economic impact of FMD outbreaks at farm level in the subsistence production systems based on data derived from case outbreaks. Chapter 4 assesses farmers' motivation to implement FMD control measures. It subsequently identifies farmers' perceptions about FMD and its control measures that have a significant influence on those motivations. Chapter 5 explores the possibility of developing a mathematical model to simulate outbreak dynamics for representative districts in the subsistence systems. Based on the information documented in the preceding chapters, Chapter 6 estimates the national costs of FMD, defines feasible control options, and analyzes the costs and benefits of the control options of FMD in Ethiopia. Chapter 7 is the concluding chapter which synthesizes the main findings of the thesis, outlines the policy implication of the main findings, highlights future research needs and draws the main conclusions on the study results.

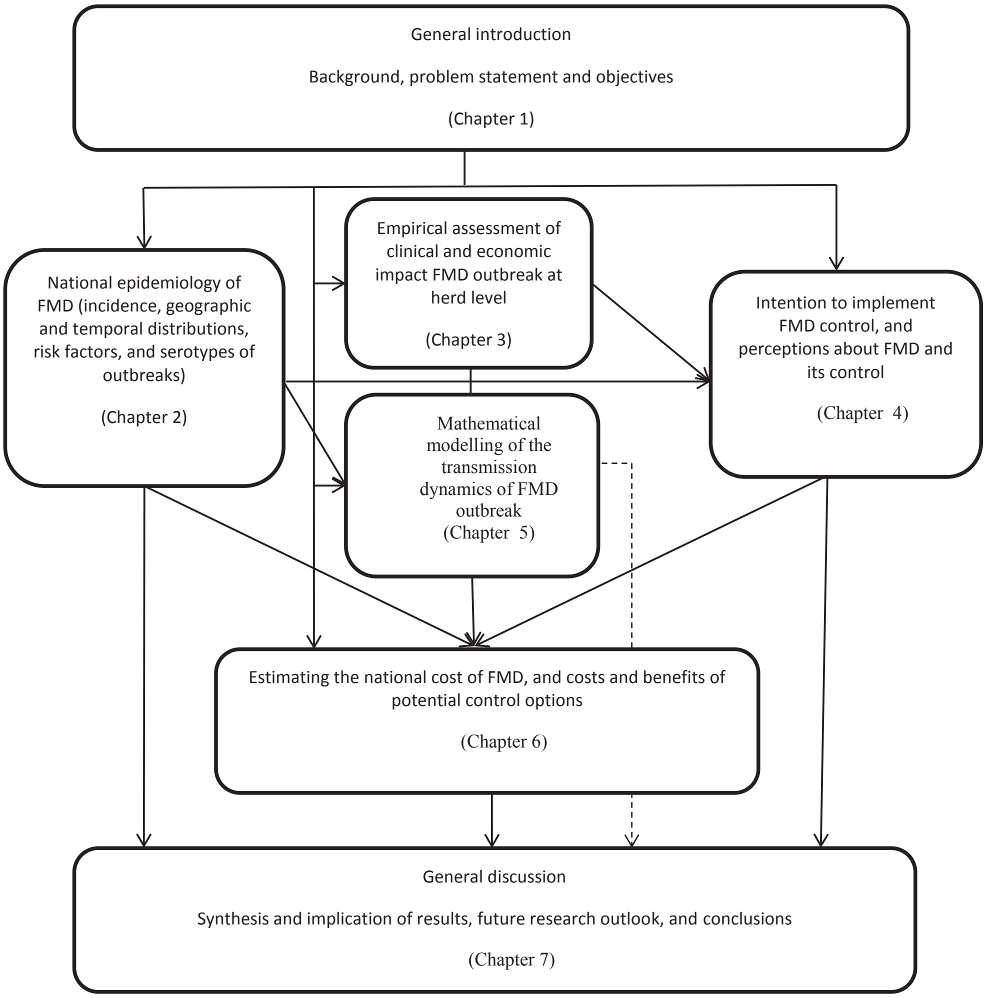

Figure 1.2. Schematic overview of structure of the thesis showing the interrelationships between the specific components of the study .

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Chapter 2

Epidemiology of Foot and Mouth Disease in Ethiopia: A Retrospective Analysis of District Level Outbreaks, 2007 – 2012

W. T. Jemberu, M.C.M. Mourits, M. Sahle, B. Siraw, J.C.M. Vernooij, H. Hogeveen

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Abstract

This study aimed at determining the incidence, distribution, risk factors and causal serotypes of foot and mouth disease (FMD) outbreaks in Ethiopia based on five years of retrospective outbreak data (September 2007 until August 2012). District level outbreak data were collected from 115 randomly selected districts using a questionnaire administered to district animal health officers. The national incidence of FMD outbreaks during the study period was 1.45 outbreaks per five district years. Outbreaks were geographically widespread affecting all major regional states in the country and were more frequent in the central, southern and southeastern parts of the country. Neither long term nor seasonal trends were observed in the incidence of outbreaks. A mixed effects logistic regression analysis revealed that the type of production system (market oriented system versus subsistence systems), presence of a major livestock market and /or route, and adjacency to a national parks or wildlife sanctuary were found to be associated with increased risk of outbreaks in the districts. FMD virus serotypes O, A, SAT 2 and SAT 1 were identified as the causal serotypes of the outbreaks during the study period. Whereas O was the dominant serotype, SAT 2 was the serotype that showed increase in relative frequency of occurrence. The estimated incidence of outbreaks is useful in assessing the economic impacts of the disease and the identified risk factors provide important knowledge to target a progressive FMD control policy for Ethiopia.

Key words: epidemiology, Ethiopia, incidence, foot and mouth disease, outbreak, risk factor

2.1 Introduction

Foot and mouth disease (FMD) is a highly contagious trans-boundary disease that affects all cloven hoofed animals. It is caused by a virus that belongs to the genus *Aphthovirus* of the family *Picornaviridae* (Mahy, 2005). Foot and mouth disease virus (FMDV) occurs in seven standard serotypes: A, O, C, and South African Territories (SAT) 1, SAT 2, SAT 3 and Asia 1. Within each serotype, many strains can be identified by genetic and immunological tests (OIE, 2012). Serotypes O and A are widely distributed, whereas serotypes SAT 1, SAT 2, and SAT 3 are normally restricted to Africa, and serotype Asia1 to Asia (Vosloo et al., 2002; Rweyemamu et al., 2008a). The occurrence of serotype C has been declining during the last 30 years and its distribution has become very limited in the recent decade; the last reported occurrence of serotype C was in Kenya in 2004 (Roeder and Knowles, 2008).

FMDVs are endemic in Ethiopia causing several outbreaks every year (Ayelet et al., 2012). Sero-surveys in different parts of the country reported sero-prevalences of 9% - 26% at the animal level and up to 48 % at the herd level in cattle (Rufael et al., 2007; Megersa et al., 2009; Bayissa et al., 2011; Mekonen et al., 2011; Mohamoud et al., 2011). Among the seven serotypes of FMDV, four (O, A, SAT 2 and SAT 1) have been reported in Ethiopia in recent times (Gelaye et al., 2005; Ayelet et al., 2009; Nigussie et al., 2011).

FMD has a broad socio-economic impact in developing countries both at macro-economic and household levels (Forman et al., 2009). The socio-economic impact of the disease could be significant in Ethiopia where livestock, in particular cattle (which constitute about 71% of the total livestock biomass), play multiple roles in the household and national economies. In addition to the conventional meat and milk products, cattle provide about 80% of draft power for the crop agriculture, manure for soil fertilizer and cooking fuel, and serve various social networking functions (MoARD, 2007; Jibat et al., 2013). Livestock is also an important foreign currency earning resource for the national economy through export of meat and live animals (Behnke, 2011).

The growing trend of private investments in the livestock sector and increase in export of live animals and meat coupled with growing international concerns on the zoosanitory importance of FMD have aroused interest in introducing control programs against the disease in Ethiopia (MoRAD, 2006). Control of FMD in endemic developing countries like Ethiopia is, however, difficult due to the complexity of the disease and the limited availability of financial resources to implement control measures (Kitching et al., 2007; Paton et al., 2009). Multiplicity of serotypes and subtypes of FMDV and diversity of its hosts make FMD control daunting. Moreover, available vaccines are expensive, fragile and provide protection for only a short period. For controlling FMD in endemic countries, a long term progressive risk reduction approach (= progressive control pathway) is advocated by FAO and OIE within the global frame work for progressive control of transboundary animal diseases (Rweyemamu et al., 2008b).

The first step within the progressive pathway for endemic countries consists of the establishment of the basic epidemiology of the disease and its socio-economic impacts. This requires, among other things, a sound knowledge of the national incidence and the geographic distribution of outbreaks, and an identification of outbreak determinants (risk factors). These insights are needed to optimize the resource use for control by targeting the husbandry systems and geographical regions where the impact of control will be greatest (Rweyemamu et al., 2008b). Knowledge of the national FMD epidemiology, upon which a good understanding of the impact of the disease and design of efficient control program can be based, is currently inadequate in Ethiopia. The objective of this study was, therefore, to obtain insight in the incidence, distribution, risk factors, and serotypes of FMD outbreaks in Ethiopia based on an analysis of five years (September 2007 until August 2012) retrospective district level outbreak data.

2.2 Materials and methods

2.2.1 Study area

Ethiopia is a big country in the horn of Africa with 1.13 million square kilometers total surface area and a human population of 86.6 million (CSA, 2013a). The country owns the largest cattle population in Africa with 54 million heads of cattle (CSA, 2013b). Ethiopia is a federation consisting of nine regional states and two city administrations. The regional states are divided into administrative zones, zones into districts and finally districts into *kebeles*. The country has a diverse ecology in its vast territory. It has a landscape ranging from a highland that peaks up to 4,620 meters above sea level in the northern highlands to lowlands of 126 meters below sea level in the north eastern Great Rift Valley region of the country. The temperature ranges from means below 0^0C in the highlands to means of above 34^0C in the lowlands. The average annual rainfall in the highlands exceeds 900 mm, while in the lowlands rainfall is erratic and on average below 600 mm (FAO, 2006).

Three types of livestock production systems can be identified in Ethiopia. The dominant production system is the crop-livestock mixed (CLM) system that prevails in the central highland parts of the country and accounts for about 80 - 85% of the cattle population and 40% of land area of the country (MoARD, 2007). In this system, cattle are owned by sedentary farmers who mainly grow crop, and cattle are primarily used for draft power in crop cultivation. The second most dominant farming system is the pastoral production system, which is practiced in the arid and semiarid peripheral parts of the country, and accounts for about 15-20% of the cattle population and 60%

of land area of the country (MoARD, 2007). In this system, livestock farming is the main livelihood and cattle are used to produce milk for the family and extra animals for the market. The third type of production system is the market oriented system which is a small but growing component of the sector in urban and peri-urban parts of the country, primarily consisting of dairy and to some extent feedlot operations. Whereas the distribution of sheep population among production systems follows roughly similar pattern to cattle, majority of goat population (70%) is found in the pastoral system and the 30% is found in the highland CLM system (MoARD, 2007).

2.2.2 Sampling design

For this study, an FMD outbreak was defined by the occurrence of one or more cases of the disease in a district as clinically diagnosed by district animal health personnel. A continuous sequence of cases within a district was considered as one outbreak unless successive cases were separated by a time gap of at least a month. Districts were, therefore, considered as the epidemiological units and hence used as unit of sampling and analysis in the study.

The district list underlying the 2007 national population and housing census was used as sampling frame. The total number of districts in this list was 731 (CSA, 2008). A stratified random sampling technique, with production system as stratifying variable, was used for sampling districts to ensure the representation of each production system. The number of districts selected from each stratum was determined by proportional allocation, where the number of districts selected is proportional to the number in each stratum (Thrusfield, 2005).

To determine the annual incidence of FMD outbreaks at district level, the sample size was calculated based on 10% expected annual district level incidence as estimated from official disease outbreak reports, 95% confidence level, and 5% desired absolute precision. The sample size was calculated using the relevant formula provided by Dohoo et al. (2009), resulting in a sample size of 138 districts. The population was, however, finite (small relative to the sample). Hence sample size was adjusted for finite population (Dohoo et al., 2009) to a size of 116 districts. Expecting a low response rate due to the possibility of selecting districts in areas of poor communication and veterinary infrastructure, an additional 20% were added, making the number of districts considered for sampling equal to140. These 140 districts were proportionally and randomly selected by stratifying the districts based on the three livestock production systems. Accordingly, 104 districts from CLM, 32 districts from pastoral and four districts from market oriented livestock production systems were selected. The distribution of selected districts in the country in the different production systems is given in Figure 2.1.

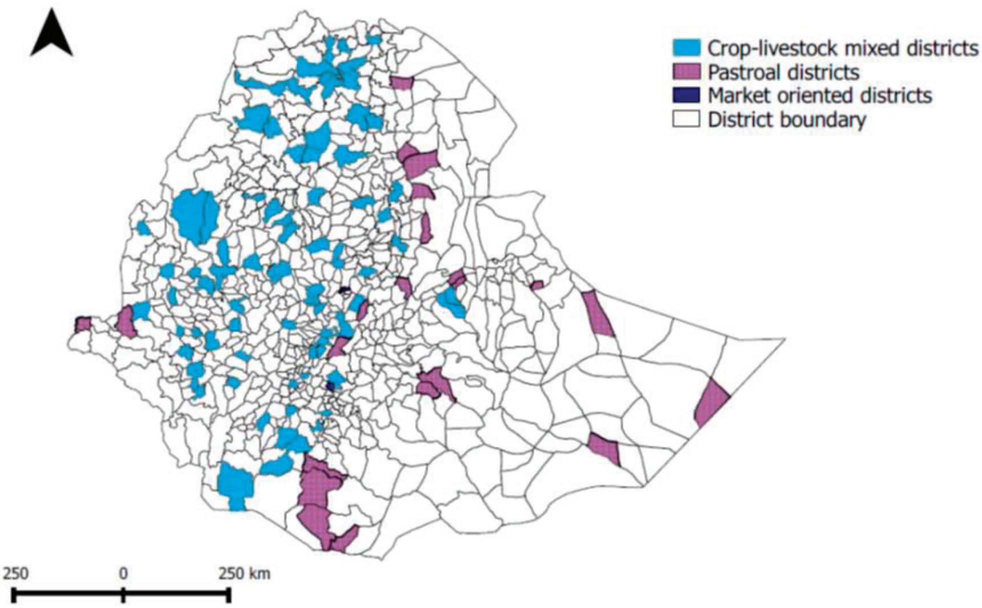

Figure 2.1 District map of Ethiopia showing the distribution of sampled districts in the different production systems.

2.2.3 Data collection

Incidence and risk factors

Data on the district level incidence of FMD outbreaks was collected retrospectively for five years from September 2007 to August 2012 (2000 through 2004 on the Ethiopian calendar) using a structured questionnaire administered to district animal health officers who were responsible to report disease outbreaks in the districts to the national veterinary authority. The questionnaire survey was preferred over the use of the official record data (as available in the veterinary services directorate disease outbreak report database) to circumvent the potential underreporting of FMD outbreaks in the official disease reports, which is considered to be common in developing countries (Sumption et al., 2008). The questionnaire was designed to be completed by animal health officers in the sample districts by the consultation of copies of monthly disease outbreak reports that were sent to the veterinary services directorate, clinic case books and animal health personnel in their respective districts. The questionnaire was administered by mail (through posts and faxes). The questionnaire was aimed at gathering information on the number of FMD outbreaks in the districts during the five-year study period, the extent to which the outbreaks were confirmed by laboratory diagnosis and serotypes were identified, and the calendar month in which the outbreaks started. Data on district level putative risk factors for incidence of FMD outbreaks such as agro-ecology, main production system, presence of a major cattle market and/or route, adjacency to a national park or wild life sanctuary, adjacency to an international border, and presence of a cross regional highway were also recorded with the questionnaire[2]. Data on district level ruminant population and density were taken from the 2001/2002 agricultural census of the Central Statistical Agency of Ethiopia (CSA, 2003), due to lack of more recent data.

FMDV Serotypes

Data on the serotypes of viruses causing FMD outbreaks diagnosed during the study period were compiled from the National Animal Health Diagnostic and Investigation Center (NAHDIC) and the National Veterinary Institute (NVI) disease outbreak investigation records. These two national laboratories collect or receive samples from FMD outbreaks all over the country, confirm the diagnosis and identify the serotypes primarily by antigen detection ELISA.

2.2.4 Data analyses

2.2.4.1 Incidence and Geographic distribution

The national district level FMD outbreak incidence was determined from the five-year data by dividing the total number outbreaks by the total number of district years.

The geographic distribution of FMD outbreaks in the country, based on the outbreak figures of the sampled districts, was mapped in two ways: by 11 administrative zones (based on regional states and city administrations) and by eight geographic zones. The geographic zones corresponds to the zonation used for the Pan African Rinderpest Campaign in Ethiopia (APHRD, 2009), and divides the country into eight roughly equivalent geographic zones. This division was based on geographic proximity that reflects biophysical and socioeconomic uniformity than political boundary (see Appendix 2.1 for the description of the geographic zones). The mapping was done using GIS software QGIS 2.2 (QGIS developer team, Open Source Geospatial Foundation, 2014).

2.2.4.2 Temporal analysis

Long term trend analysis

A linear regression, with monthly time intervals as predictors and monthly outbreak number as outcome variable, was fitted to identify the presence of a long term linear trend in the incidence of FMD outbreaks (Thrusfield, 2005). The data was first explored for the presence of autocorrelation using autocorrelation function and subsequently corrected for first order autocorrelation by Cochrane-Orcutt procedure using package "orcutt" (Spada et al., 2014) in R software version 3.0.2 (R Core Team, 2013). The linear regression model showed a poor fit of the data, indicating absence of an explicit long

2 The questionnaire is available upon request from the corresponding author

term linear trend. By rejecting the long term linear trend, the incidences in the different years were subsequently compared using a mixed effects logistic regression with effect coding of the categorical variable year; and with district as random effect to account for the correlation between the observations within districts.

Seasonal trend analysis

Based on the rainfall regimes, there are three seasonal patterns in Ethiopia (Bekele, 1993): 1) a two-season pattern with a wet season from June to September and a dry season from October to May that is prevalent in the western half of the country, 2) a three-season pattern with two wet seasons from June to September (main rain) and from February to May (small rain), and one dry season from October to January that is prevalent in the central and most of the eastern part of the country, and 3) a four-season pattern with two wet seasons from March to June and September to November, and two dry seasons from December to February and July to August that is prevalent in the south and southeastern parts of the country. The difference between the two-season and the three-season pattern is only an additional few months of light rain in the three-season pattern, and hence the latter was combined with the former for convenience in this study. Therefore, two separate seasonal analyses were made: for the two-season pattern and for the four-season pattern using the outbreak incidence data from the respective regions.

Seasonality was assessed for each of the two seasonal patterns separately by plotting three months moving averages of outbreak numbers over the 60 months of the five-year study period. The moving average was used to reduce random variation and to ease the detection of underlying trends (Thrusfield, 2005). Randomness in the patterns of monthly number of FMD outbreak occurrences was further tested by using Runs test for test of randomness (Corder and Foreman, 2014).

2.2.4.3 Risk factor analysis

Given the collected data, the maximum incidence in every district appeared to be only one outbreak per year. So, given a time frame of a year, FMD occurred or not (i.e.1/0). Hence, a logistic model was used for the risk factor analysis with "occurrence" or "nonoccurrence" of an FMD outbreak in a district in a particular year as the outcome variable.

The outcome variable, however, consisted of repeated measures due to the recording of FMD occurrences within each district for five successive years. To account for any clustering of data (occurrences) within districts and years, a mixed effects logistic regression model was used with district and year as random effects in analyzing the district level risk factors for the incidence of FMD outbreaks (Dohoo et al., 2009). The model was formulated as

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + u_{district} + u_{year}$$

Where π is the probability of occurrence of FMD outbreak per district per year, X's are predictors included as fixed effects and β's their corresponding estimated coefficients, $u_{district}$ and u_{year} are random effects for district and year, respectively.

A total of 10 predictor variables were analyzed as putative risk factor of FMD (Table 2.1). The variable 'outbreak in the neighbor district(s)' was included to estimate the risk of outbreak transmitted from the neighbor(s) and to control for the possible spatial dependence among the responses of neighboring districts. Ruminant density predictor variables (cattle, sheep and goat densities) were originally recorded in a continuous scale. Preliminary analysis, however, showed that their relations to the log odds of the outcome variable were not linear and hence the variables were categorized. Due to absence of clear natural breaks in the data points each of the three variables was categorized into three categories based on their corresponding three quantile densities: low for the first quantile, medium for the second quantile and high for the third quantile. In categorical predictor variables, categories with the largest frequency were treated as reference category. Before running the model, the predictor variables were checked for multicollinearity. Presence of multicollinearity was considered at variance inflation factors greater than 10 (Dohoo et al., 2009).

The mixed effects logistic regression model was fitted using lme4 package (Bates et al., 2014), in R software version 3.0.2 (R Core Team, 2013). Function "dredge" from the MuMIn package (Barton, 2014) was then used to rank all possible models based on the corrected Akaike's Information Criterion (AICc) and the model with smallest AICc was selected as best model.

Table 2.1. Description of districts with respect to predictor variables (putative risk factors) and outbreak incidence

Putative risk factors	Categories	No. of districts per category	Outbreak incidence per district year
Agroecology	Highland (> 2,300 *masl)	12	0.28
	Midland(> 1,500 masl and <2,300 masl)	62	0.37
	Lowland (<1, 500 masl)	35	0.25
Adjacency to national park/wild life sanctuary	No	91	0.26
	Yes	18	0.42
Adjacency to international border	No	102	0.28
	Yes	7	0.37
Presence of cross regional motor highway	No	28	0.23
	Yes	81	0.31
Presence of major cattle market and / or route	No	36	0.17
	Yes	73	0.35
Production system	Crop-livestock mixed	83	0.24
	Pastoral	22	0.39
	Market oriented	4	0.85
Cattle density	Low (first quantile (<41 / km^2))	37	0.29
	Medium (second quantile (41-92 / km^2))	36	0.30
	High (third qauntile (> 92 / km^2))	36	0.29
Sheep density	Low (first quantile (<9 / km^2))	37	0.36
	Medium (second quantile (9-27 / km^2))	36	0.21
	High (third qauntile (>27 / km^2))	36	0.30
Goat density	Low (first quantile (<10 / km2))	36	0.27
	Medium (second quantile(10-25 / km^2))	36	0.38
	High (third quantile (>25 / km^2))	37	0.22
**Outbreak in the neighbor district(s)	Yes (outbreak occurred and if outbreak occurred in the district, the outbreak in the neighbor occurred earlier)	94	0.42
	Unknown (no neighbor district or the outbreak occurred at the same time with the district)	227	0. 26
	No (no outbreak occurred or outbreak occurred later than in the district)	224	0.26

*masl = meters above sea level

** The variable was recorded in each of the five years and this makes the number of districts 545(109 district*5 years).

2.3 Results

2.3.1 Questionnaire response rate and data reliability

From the 140 districts to which questionnaires were sent for collecting FMD outbreak data, 115 district animal health officers responded giving a response rate of 82 % with roughly similar response rates in all production systems. Data from six districts were discarded for lack of quality (inconsistency and incompleteness) leaving 109 districts with complete and consistent information. From these 109 districts, a total of 158 district level outbreaks were documented retrospectively over the five years. During the same period, only 47 district level outbreaks were recorded in the veterinary services directorate disease report database for the study districts. Crosschecking of the questionnaire data with the outbreak reports in the disease report database revealed that 33 (70%) of the 47 registered outbreaks were correctly documented by the questionnaire. This proportion was higher in the year 2011/12 (83%) than in the other years (average 68%). On the other hand, the 47 outbreaks reported by the regular passive reporting system covers only 30% of the presumably 158 outbreaks that occurred in the districts during the study period as documented by the questionnaire.

2.3.2 FMD outbreak incidence

From the total of 109 districts used for the analysis, about 73% experienced an FMD outbreak at least once during the five year study period and 5% reported an outbreak of the disease every year. The modal outbreak incidence was one outbreak per five years which happened in 36% of the districts. The national average incidence of district level FMD outbreak was 1.45 per five district years or 0.29 per district year, which indicates that on average about 30% of districts in the country are affected by an FMD outbreak every year.

2.3.3 Geographical distribution of outbreaks

The geographical distribution of five years of FMD outbreaks within the regional states is depicted in Figure 2.2. FMD outbreaks occurred in all regional states except in Dire Dawa city administration and Harare regional state from which no district was included in the sample. The highest incidence of district level FMD outbreak was seen in the Addis Ababa city administration (4/ five district years) followed by Gambella regional state (3/five district years). Mapping the disease by the eight geographical zones showed that the FMD outbreak incidence was above the national average in southeastern (2.67/ five district years), central (2.28/five district years), and southern (1.88/five district years) parts of the country (Figure 2.3).

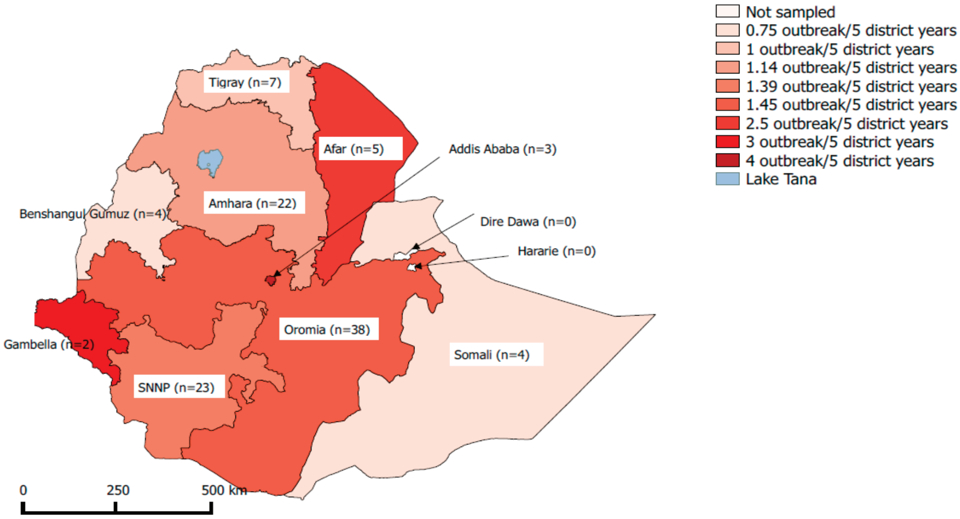

Figure 2.2. Choroplethic map of the incidence of FMD outbreaks per five district years within the 11 regional states and city administrations of Ethiopia. SNNP = South nation, nationalities and peoples region.

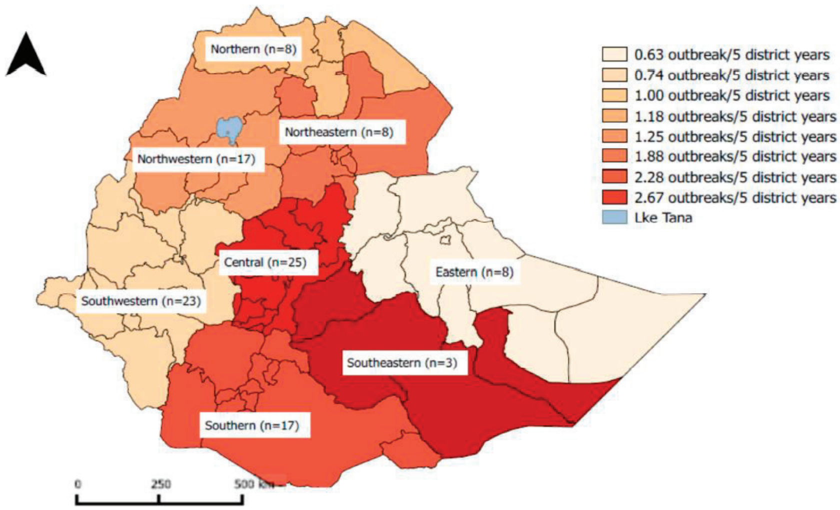

Figure 2.3. Choroplethic map of incidence of FMD outbreaks per five district years within the eight geographical zones in Ethiopia.

2.3.4 Temporal analysis

Neither a significant long term trend nor a seasonal pattern was identified in the incidence of district level FMD outbreaks over the five years study period. The linear regression model adjusted for first order autocorrelation, which was found to be r1 = 0.418, showed poor fit of the data (R^2 = 0.41), indicating absence of an explicit long term linear trend. Runs test for test of randomness indicated no significant seasonality of outbreak occurrence for both the four-season pattern in the southern and southeastern part of the country ($p = 0.225$) and the two-season pattern in the rest of the country ($p = 0.077$) (see Appendix 2.2, Figures A2.2.1 and A2.2.2 for three-monthly moving average plots of FMD outbreak occurrence). Accounting for the random effect of districts, there was, however, variation in the incidence of FMD over the five years (Figure 2.4). There were higher numbers of FMD outbreaks in the year 2011/12 ($P < 0.001$) and the year 2007/8 ($P = 0.14$) compared with the mean number of outbreaks per year.

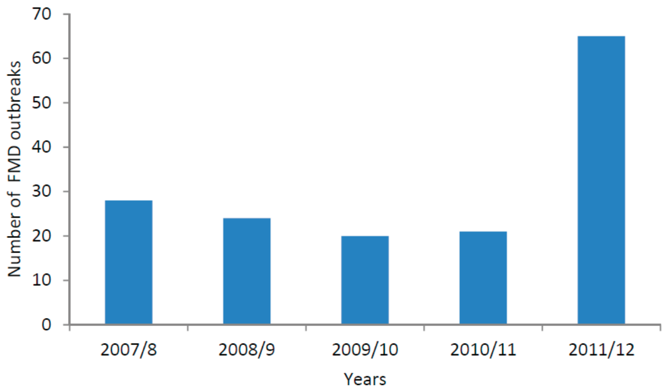

Figure 2.4. Annual number of district level FMD outbreaks during the five years of the study period.

2.3.5 Risk factor analysis

The description of study districts with respect to the 10 predictor variables (putative risk factors) and outbreak incidence is provided in Table 2.1. The distribution of districts showed high disparity with respect to some of the predictor variables. For example, there were relatively few districts that were adjacent to international borders and national parks compared with their counterparts.

As no multicollinearity was found between the predictor variables (variance inflation factors less than 10), a mixed effects logistic regression model with district and year as random effects was fitted on all the 10 predictor variables. The best model, selected by an automatic model selection procedure based on the AICc criterion, included five risk factors that explain the variation in the incidence of district level FMD outbreaks (Table 2.2).

Table 2.2. The best fit risk factor model with the coefficients, odd ratio (OR) and statistical significance of the coefficients. (Inter-district Variance = 0.5439; Inter - year variance = 0.7793)

Risk factors	Categories	Coefficients	Standard Error	Odds Ratio (95% CI)	P-value
Intercept		-1.85	0.518		0.0003
Park/wild life sanctuary	Yes	0.79	0.354	2.20 (1.10-4.41)	0.0250
	No		1	1	
Livestock market and /or route	Yes	0.92	0.317	2.51 (1.35-4.67)	0.0039
	No		1	1	
Production system	Market oriented	3.35	0.869	28.50(5.19-156.53)	0.0001
	Pastoral	0.23	0.372	1.26 (0.61-2.61)	0.5339
	Crop-livestock mixed		1	1	
Sheep density	High	-0.72	0.408	0.49 (0.22-1.08)	0.0784
	Medium	-0.90	0.351	0.41 (0.20-0.81)	0.0104
	Low		1	1	
Goat density	High	0.02	0.396	1.02 (0.47-2.22)	0.9552
	Medium	0.77	0.361	2.16 (1.06-4.38)	0.0330
	Low		1	1	

The model showed that, after adjusting for the effect of other factors, a higher odd of experiencing an FMD outbreak was observed in districts where the main farming system was market oriented (OR= 28.50, 95% CI = 5.19-156.53) compared with districts where the main farming system was CLM; in districts with a livestock market and/or route (OR = 2.51, 95% CI = 1.35-4.67) compared with those without a livestock market and/or route; and in districts that were adjacent to a national park or wildlife sanctuary (OR= 2.20, 95% CI = 1.10-4.41) compared with those that were not. Whereas medium density of sheep was significantly associated with decreased risk of FMD (OR = 0.41, 95% CI = 0.20-0.81), medium density of goats was significantly associated with an increased risk of FMD (OR = 2.16, 95% CI = 1.06-4.38) compared with low densities in the respective species (Table 2.2).

2.3.6 FMDV serotypes

National disease outbreak investigation records from NVI and NADIC showed that FMD outbreaks that occurred in the five years period were caused by serotypes O, A, SAT 1 and SAT 2 (Table 2.3). The most dominant serotype was O accounting for 70% of 173 samples that tested positive (n=379), followed by SAT 2 with 20.8 %.

Table 2.3. Serotypes of FMDVs causing FMD outbreaks from 2007/8 through 2011/12

Year	No. samples	Positive samples	Serotypes identified	serotype frequency	Sample origin*
2007/8	98	21	O	13	SNNP** (Koka, Surma, Sheka, Yeki),
			A	3	Benshangul Gumuz, Debre Zeit, Addis
			SAT 1	5	Ababa
2008/9	45	25	O	19	Addis, Ababa, Debre Zeit, Bahir Dar
			A	6	
2009/10	77	52	O	31	Addis Ababa, Harar, Debre Birhan
			A	2	Sululta
			SAT 2	19	
20010/11	44	28	O	11	East Shoa, Bahir Dar, Arbaminch
			SAT 2	17	
2011/12	115	47	O	47	Oromia (Abaya, Borena, Dama, Guji, Adama), Addis Ababa, Mekelle, Amhara (Jille Timuga, Kombolcha), SNNP (Wollayta Sodo, Sidama), Tigray (Mekele).
Total	379	173	O	121	-
			A	11	
			SAT 1	5	
			SAT 2	36	

* Specific location for every sample was not available.
**SNNP = South nations, nationalities and peoples region
(Compiled from NADHIC and NVI disease investigation records)

1.4 Discussion and conclusions

This study was based on retrospective outbreak data collected through a questionnaire among district animal health officers. Questionnaire data were preferred over the official record data to circumvent the potential underreporting of FMD cases in the official disease reports, which is considered to be common in developing countries (Sumption et al., 2008). This study confirms a significant underreporting of FMD cases in the regular passive surveillance system of Ethiopia. Only 47 FMD outbreaks were recorded for the study districts in the official disease record of the veterinary services directorate compared with 158 outbreaks documented by the questionnaire. However, courtesy bias with respect to the provided responses cannot be excluded, which means a risk of over-reporting of the number of outbreaks. Moreover, the questionnaire data, which were collected retrospectively, might raise reliability concerns related with recall bias. Crosschecking of the questionnaire data with the official recorded data, however, showed that 70% of the outbreaks recorded in the official record were correctly documented by the questionnaire, which assures a reasonable confidence on the reliability of the data.

The study showed that, on average, about one-third of the districts in the country were affected by an FMD outbreak every year. To our knowledge, district level outbreak incidence estimates in literature are limited to directly compare with our findings. However, our estimate seems lower than outbreak incidences reported at herd level in other endemic countries like in Cameroon where 58% of the study herds reported FMD in a year (Bronsvoort et al., 2004), and in Thailand where more than two thirds of the herds reported two or more FMD outbreak in five years (Cleland et al., 1996). The 73% of districts which reported at least one outbreak in five years in this study was roughly comparable to a similar report from Bhutan where 62% of studied villages experienced at least one FMD outbreak in five years (Dukpa et al., 2011a).

FMD has been reported from all major regional states in Ethiopia. A previous study that covered a period prior to the current study period identified two regional states (Gambella and Benshangule Gumuz) to be serologically FMD free and suggested them as candidate for establishing FMD free zones in the country (Ayelet et al., 2012). The present study, however, showed that they are equally affected by the disease and currently no part of the country seems free of the disease. Addis Ababa, Gambella and Afar were the regional states with the highest incidence. Comparison of the disease distribution on regional states has, however, a limited epidemiological significance as regional states are politically defined and, therefore, missing uniformity in epidemiological features. An epidemiologically more useful disease distribution was mapped on the eight geographical zones which have been used as coordination centers during the pan African rinderpest campaign in Ethiopia (APHRD, 2009). These zones are relatively more uniform in terms of biophysical and socio-economic environments, and have a geographical closeness that could influence the disease epidemiology. Based on this zonation, FMD outbreaks were more common in the central, southern and southeastern parts of the country. The high incidence in central Ethiopia could be associated with trade animal movements. Trade animal movements are normally related to differences in livestock and meat prices (Rushton, 2008). In Ethiopia prices are higher in urban centers, the largest of which is Addis Ababa that is found in the center of the country, and livestock usually move towards the center from other parts of the country. The southern and south eastern parts of the country are the main areas for cattle pastoralism and are also the main source of export animals. The higher incidence in these areas could be due to intensive animal movement both as a normal routine of the pastoral husbandry system and for the purpose of trade.

Temporal patterns of disease outbreaks are decomposed into long term (secular), cyclical and seasonal trends (Peralta et al., 1982; Courtin et al., 2000; Gallego et al., 2007). The five year period in this study was too short to formally analyze the cyclical pattern and only long term and seasonal trends were analyzed. The temporal analysis showed neither a long term nor a seasonal trend in the FMD outbreak incidence. There were, however, variations in the incidence of outbreaks in the different years. A higher incidence was observed in the years 2007/8 and 2011/12, indicating the possibility of an epidemic pulse every four years. Two studies that together covered a 10 years continuous period prior to the current study period showed a large number of FMD outbreaks in 1999 (Asfaw and Sintaro, 2000) and in 2004 (Ayelet et al., 2012). These findings combined with the present data suggest a three to four years cyclic pattern. FMD epidemics have been shown to occur with a regularity of three to five years in Paraguay and Colombia (Peralta et al., 1982; Gallego et al., 2007) and every six years in India (Sharma and Singh, 1993). In the absence of any control measure applied, highly contagious diseases like FMD tend to occur with regular epidemic cycles related to the increase of the susceptible population through time (Thrusfield, 2005).

Five putative risk factors viz. production system, presence of a major livestock market and/or route, adjacency to a national park or wild life sanctuary, and sheep and goat densities were found significantly associated with the risk of FMD outbreaks in the districts.

Districts that are characterized mainly by market oriented cattle production were more affected than districts with primarily subsistence systems. These market oriented districts were found in major urban centers like in Addis Ababa and Hawassa. In these districts, the presence of the disease was reported almost every year. Similarly, FMD outbreaks have been reported to occur every year in Bishoftu town in central Ethiopia, where urban dairying is abundantly practiced (Beyi, 2012). The higher incidence of FMD could be associated with the susceptibility of improved exotic breeds that are kept in this type of production system. Improved dairy cattle breeds are very susceptible to FMD and are even difficult to protect by frequent vaccination (Kitching, 2002). Moreover, this type of production system is found in urban and peri-urban areas where there is a high livestock marketing activity through which infections are introduced and spread. This is especially apparent during holidays in Ethiopia when animals are trekked and trucked towards urban centers from distant rural areas. Market oriented production in the urban and peri-urban areas can, therefore, be targeted for intensive FMD control to reduce high production losses from high yielding susceptible animals.

The other important district level risk factor identified was the presence of a major livestock market and/or route. This could be associated with trade animal movements.

Livestock movement has been shown to be one of the most important risk factors for FMD in endemic countries (Cleland et al., 1996; Bronsvoort et al., 2004; Rweyemamu et al., 2008a; Ayebazibwe et al., 2010; Fasina et al., 2013). In tropical endemic areas where high temperature and low humidity disfavor airborne transmission, it is suspected that the main mode of transmission of FMD is through contact of infected and susceptible animals (Sutmoller et al., 2003) that would be facilitated by uncontrolled animal movement. This indicates the importance of animal movement regulations for reducing the prevalence of the disease in the country.

Adjacency to a national park or sanctuary was associated with a higher district level outbreak incidence. A similar association was reported in other countries (Bronsvoort et al., 2004; Ayebazibwe et al., 2010). Although many wild ungulates are known to be susceptible to FMD, their role in the epidemiology of FMD is considered less significant, except for the African buffalo (*Syncerus caffer*) (Bastos et al., 2000; Thomson et al., 2003). The association between FMD incidence and wildlife parks could, therefore, be primarily related to buffalos which are known to be a natural reservoir for SAT viruses (Thomson et al., 2003). The association found between national parks and FMD outbreaks in the present study is in line with the fact that SAT serotypes were first reported in the southern and southwestern Ethiopia where national parks with buffalo populations (Omo and Gambella national parks) are found. A previous serological investigation of the role of wildlife in the epidemiology of FMD in Ethiopia also found buffalos as the only true serological reactors with respect to FMD (Sahle, 2004). These findings may indicate the potential importance of buffaloes in the epidemiology of the disease in Ethiopia. However, given the highly prevalent and uncontrolled FMD occurrence in the livestock population, the relative dominance of non-SAT viruses and the limited geographical area where buffalos are present in Ethiopia, the role of wildlife in FMD epidemiology could be of minor importance during the studied period.

The results of the analysis related to ruminant densities observed in this study are inconsistent with literature information. Cattle density has been indicated to be associated with a high frequency or spread of FMD outbreaks (Bessell et al., 2010; Dukpa et al., 2011b). No such association was found in the present study. The observed nonlinear association of FMD risk with sheep and goat density, in which medium densities in the respective species were associated with low and high risks of FMD compared with the low densities, is difficult to explain within the existing knowledge. These unexpected findings might have to do with the dubious quality of the ruminant population data which was taken from an old source (2001/2 livestock census).

Although not all outbreaks that occur in the country were sampled for laboratory diagnosis, those recorded can give a rough picture about prevalence and relative frequency of the serotypes in the country. The most frequently diagnosed type during the five-year period was serotype O accounting for about 70% of all the samples that yielded positive diagnoses. It, not only, occurred frequently, it was also widely distributed geographically. Serotype O was followed by SAT 2 with a proportion of 21%. During the studied period serotype SAT 2 has overtaken the rank of serotype A, which used to be reported as the second most dominant serotype in the country (Gelaye et al, 2005; Ayelet et al., 2009). This underscores the importance of inclusion of SAT 2 virus in the present FMD vaccine cocktail. The period was also a time in which the newest serotype, SAT 1, was isolated for the first time in the country in 2007 from an outbreak in southwest Ethiopia. The SAT 2 was first reported in 1989 in Borena region of southern Ethiopia (Roeder et al., 1994). The SAT 1 and 2 serotypes were diagnosed relatively recently in Ethiopia and both of them were first detected in the south and southwest parts of the country. These serotypes still have not been diagnosed in the northern half of the country (north of North Showa). A previous serological study also indicated that SAT viruses had been limited to southern Ethiopia (Borena and Southern Showa zones) (Sahle, 2004), which is even less than the present geographical distribution. Movement restriction during outbreaks should, therefore, limit the spread of these serotypes further to the north of the country. The other implication of this serotype distribution is the directed use of vaccine serotypes in different parts of the country to minimize the cost of vaccination that arise due to inclusion of additional serotypes.

In general, this study explored useful epidemiological information to support national decision making regarding FMD control. However, it should be acknowledged that the study has a possible reporting bias due to the use of a questionnaire data rather than a prospective collection of objective data. To determine the annual incidence of FMD outbreaks at district level, the sample size of 138 districts was calculated based on a 10% expected annual district level incidence as estimated from official disease outbreak reports, a 95% confidence level, and a 5% desired absolute precision level. The annual incidence found in this study was, however, about 30%, indicating a lower precision (7.7%) of the estimates than that was aimed for (5%). The study has a low geographical resolution because of use of districts as sampling units, which themselves are not strictly uniform entities. Whereas using district as sampling units facilitated getting of an overview of countrywide epidemiology of the disease, smaller sampling units could have exposed more detailed patterns and risk factors of the disease incidence.

The estimated magnitude and distribution of outbreak incidence can provide basis for the assessment of the disease impact in the different production systems in Ethiopia. The geographic distribution of the disease and the risk factors identified could be useful inputs for strategic planning of the disease's control. This knowledge is important for designing a progressive control of FMD which has an underlying principle of a step by step reduction of disease impact and virus load, by targeting of measures to geographic regions and production sectors where the impact on disease control and/ or virus circulation will be greatest. Accordingly intensive FMD control can start in the central and southern parts of the country. Urban and peri-urban areas where market oriented production are practiced and areas along major livestock trade routes could be priority areas for application of control measures to reduce the economic losses from high production sectors and for curbing extensive dissemination of outbreaks. However, given the limitations of the study discussed in the preceding paragraph, the suggested approaches may not be conclusive enough and follow-up studies are needed to evaluate the effectiveness of these approaches. Moreover, effective control of FMD using vaccination requires a clear picture of the specific frequency, distribution and maintenance of serotypes and subtypes of viruses causing the outbreaks, which was only marginally dealt with in this study.

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Appendixes

Appendix 2.1: Description of the eight geographic zones in terms of present political boundaries of administrative zones and special districts.

1. Northern Ethiopia (Mekele): Tigray region and northern part (Zone 2) of Afar region.
2. Northeastern Ethiopia (Kombolcha): North Wollo, South Wollo, Oromia and Waghemra Zones of Amhara region; and middle part (zone 1 and Zone 4) of Afar region.
3. Northwestern Ethiopia (Bahir Dar): North Gondar, South Gondar, west Gojjam, Awi and East Gojam Zones of Amhara region, and northern part (Metekel zone and Pawe special district) of Benshangul Gumuz region.
4. Central Ethiopia (Addis Ababa): North Showa of Amhara region, southern part (Zone 3 and Zone 5) of Afar region; North showa, West Showa, Southwest Showa and East Showa zones of Ormoia region; and Gurgie, Silitie, Hadya and kembata Zones and Yem and Alaba special districts of South nation nationalities and peoples region.
5. Southwestern Ethiopia (Bedele): Southern part (Kemashi and Assosa zones and Mao komo special district) of Benshangule region; Kelem Wollega, West Wollega, Horodgudru, East Wollega, Jimma and Illuababora zones of Oromia region; Gambella region; Benchi Maji, Sheka, and Keffa zones of South nation nationalities and peoples region.
6. Eastern Ethiopia (Harar): West Hararghe and East Hararghe zones of Ormoya region, Dire Dawa city administration; Hararie region; and Shinile, Jijga, Fik, Deghabour, Korahe and Warder zones Somalie region.
7. Southeastern Ethiopia (Dodola): West Arsi, Arsi and Bale zones of Oromia region, and Afder and Gode Zones of Somalie region
8. Southern Ethiopia (Hawasa): Wollayta, Dawro, Sidama, Gedeo, Gamo Gofa, South Omo zones and Konta, Basketo, Amaro, Burji, Konso and Derashe special districts of South nations nationalities and peoples region; Borena and Guji zones of Oromia region; and Liben zone of Somalie region.

Appendix 2.2. Three-monthly moving average occurrence of FMD outbreak in the two-season and four-season areas of the country

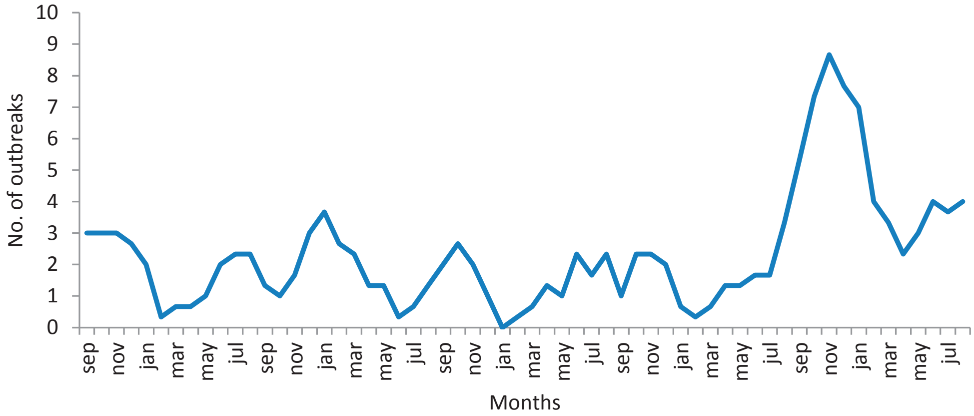

Figure A2.2.1. Five years (2007/8-201/12) three-monthly moving average occurrence of FMD outbreaks in the two-season areas of the Ethiopia.

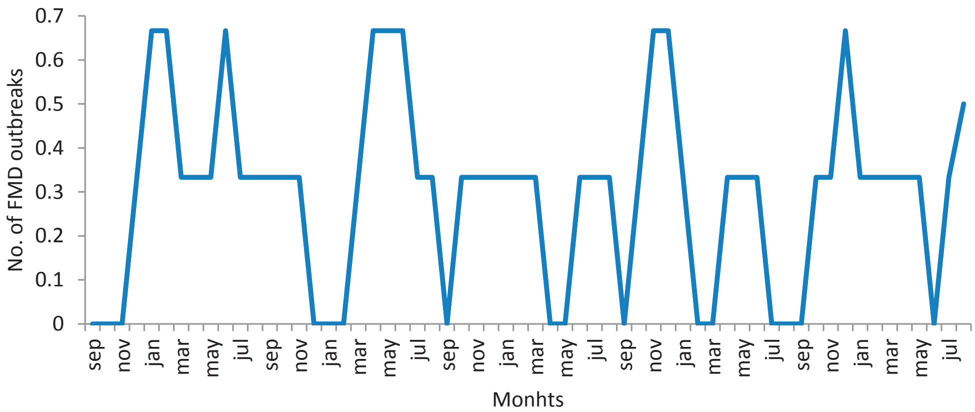

Figure A2.2.2. Five years (2007/8-201/12) three-monthly moving average occurrence of FMD outbreaks in the four-season areas of the Ethiopia.

Chapter 3

Clinical and Economic Impact of Foot and Mouth Disease Outbreaks on Smallholder Farmers in Ethiopia

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Abstract

Foot and mouth disease is endemic in Ethiopia with occurrences of several outbreaks every year. Quantitative information about the impact of the disease on smallholder farming systems in the country is, however, scarce. This study presents a quantitative assessment of the clinical and direct economic impacts of foot and mouth disease on household level in smallholder livestock farming systems. Impacts were assessed based on data obtained from case outbreaks in cattle in crop-livestock mixed and pastoral smallholder farming systems that occurred in 2012 and 2013. Data were collected by using questionnaires administered to 512 smallholder farmers in six districts within two administrate zones that represent the two smallholder farming systems. Foot and mouth disease morbidity rates of 85.2% and 94.9% at herd level; and 74.3% and 60.8% at animal level in the affected herds were determined for crop-livestock mixed system and pastoral system, respectively. The overall and calf specific mortality rates were 2.4% and 9.7% for the crop-livestock mixed system, and 0.7% and 2.6% for the pastoral system, respectively. Herd level morbidity rate was statistically significantly higher in the pastoral system than in the crop-livestock mixed system ($P < 0.001$). The economic losses of foot and mouth disease due to milk loss, draft power loss and mortality were on average USD 76 per affected herd and USD 10 per head of cattle in the affected herds in crop-livestock mixed system; and USD 174 per affected herd and USD 5 per head of cattle in the affected herds in the pastoral system. The herd level economic losses were statistically significantly higher for the pastoral system than for the crop-livestock mixed system ($P < 0.001$). The major loss due to the disease occurred as a result of milk losses and draft power losses whereas mortality losses were relatively low. Although the presented estimates on the economic losses accounted only for the visible direct impacts of the disease on herd level, these conservative estimates signify a potential socioeconomic gain from a control intervention.

Key words: cattle, economics, Ethiopia, foot and mouth disease, morbidity, smallholder farming system

3.1 Introduction

Livestock production has a significant role to the Ethiopian economy by contributing up to 45% of the agricultural GDP, 19% of total GDP and one fifth of the country's export (Behnke, 2011). Within the livestock population of the country, cattle represent about 71% of the total 42.2 million tropical livestock units (livestock biomass) (MoARD, 2007). Cattle production in Ethiopia occurs mainly in subsistence oriented small holder farming systems. Within these systems, cattle play an essential role at household level by providing milk and meat for food, draft power, manure for soil fertilizer and cooking, cash income, and other economic and social functions like financial security and matrimonial dowry. Crop-livestock mixed (CLM) farming is the dominant farming system in which about 80-85% of the national cattle population is kept. The primary purpose of cattle in this system is to provide draft power for crop production. In Ethiopia 80% of the required traction power for crop agriculture is provided by oxen (MoARD, 2007). Pastoral farming is the second most important farming system, which represents about 15-20% of the national cattle population. Cattle in this system are mainly kept for milk production for household consumption. The third is market oriented farming system, which mainly consists of dairy and fattening, and represents only a small proportion of the national cattle population.

Foot and mouth disease (FMD) is one of the endemic diseases in Ethiopia that occurs recurrently, causing several outbreaks every year (Ayelet et al., 2012). Serological surveys reported a sero-prevalence that ranges from 5% to 25% at the animal level and up to 60% at the herd level in different parts of the country (Rufeal et al., 2008; Megersa et al., 2009; Bayessa et al., 2011).

Foot and mouth disease is considered as the most important livestock disease in the world in terms of its economic impact (James and Rushton, 2002). The annual economic impact of FMD in terms of visible production losses and vaccination costs in endemic regions of the world is estimated between US$6.5 and 21 billion, while outbreaks in FMD free countries and zones cause losses of more than US$1.5 billion a year (Knight-Jones and Rushton, 2013). The economic impact of FMD in endemic areas can be separated into two components: direct and indirect losses (Rushton, 2009; Knight-Jones and Rushton, 2013). The direct losses of the disease consist of loss of milk production, loss of draft power, retardation of growth, abortion and delayed breeding, and mortality especially in young animals. The indirect losses are related to market restrictions, use of suboptimal production technologies and costs of control.

Foot and mouth disease is commonly considered as mild in indigenous animals in the traditional productions systems (James and Rushton, 2002; Vosloo et al., 2002; Thomson and Bastos, 2005), implying a limited economic significance of the disease for smallholder subsistence farmers who keep indigenous animals and do not participate in the international trade. However, the importance of the disease for the smallholder farmers has been controversial. For example, Perry et al. (2003) claimed a pro-poor impact of foot and mouth disease control in the southern African region through a national economic growth that would create a suitable base for poverty reduction. Scoones and Wolmer (2006), however, commented that although this study clearly showed that the investment in FMD control primarily benefits the commercial sector, the researchers inappropriately concluded that the poor would benefit indirectly from the national economic growth. In a subsequent paper, Perry and Rich (2007) indicated that FMD has diverse impacts across different farming systems and that its control would constitute a pro-poor investment in many developing countries. Meanwhile, several case outbreak studies that were conducted in different parts of the world reported a significant impact of FMD in the smallholder settings (Barasa et al., 2008; Rast et al., 2010; Shankar et al., 2012; Young et al., 2013).

Quantitative information on the impact of FMD is essential in order to make sound decisions about its control. Although it can be conjectured that losses from FMD in Ethiopia could be significant due to the multiple functions of cattle in the smallholder farming systems, empirical estimates about such losses are scarce. This study presents an empirical case study of the clinical and direct economic impact of FMD outbreaks on household level in the smallholder livestock farming systems in Ethiopia.

3.2 Materials and Methods

3.2.1 Study areas

The study was conducted in the administrative zones of North Wollo and Borena (Figure 3.1). These zones were selected for their representation of the two main smallholder farming systems in Ethiopia and their recent FMD outbreak experience.

North Wollo is located in northeast Ethiopia. The agro-ecological landscape within North Wollo ranges from drier lowlands at about 1,000 meter above sea level, through fertile midlands, to cold highlands as high as 3,700 meter above sea level (Ege and Adal, 2000). The main livelihood within this zone is crop-livestock mixed (CLM) farming. Cattle are primarily kept on smallholdings where they provide draft power for crop production, manure for soil fertility and fuel, family diet, and cash income. The study within the North Wollo zone was concentrated on the districts of Kobo, Guba Lafto and Habru as these three districts were recently affected by an FMD outbreak that occurred from June to November 2012.

Borena zone is located in southern part of the country. Except for a central mountain range and scattered volcanic cones and craters, the zone's landscape is gently undulating across an elevation of 1,000 to 1,600 meter (Coppock, 1994). The zone is dominated by a semi-arid climate and most parts of the zone are less endowed with moisture for reliable crop based livelihoods. The main livelihood in this arid and semi-arid region is pastoralism. Three representative districts namely Dugda Dawa, Yabello and Dire were used for the study. These pastoral districts were selected based on their recent history of experiencing a FMD outbreak that occurred from December 2012 to February 2013 and on their accessibility for investigation.

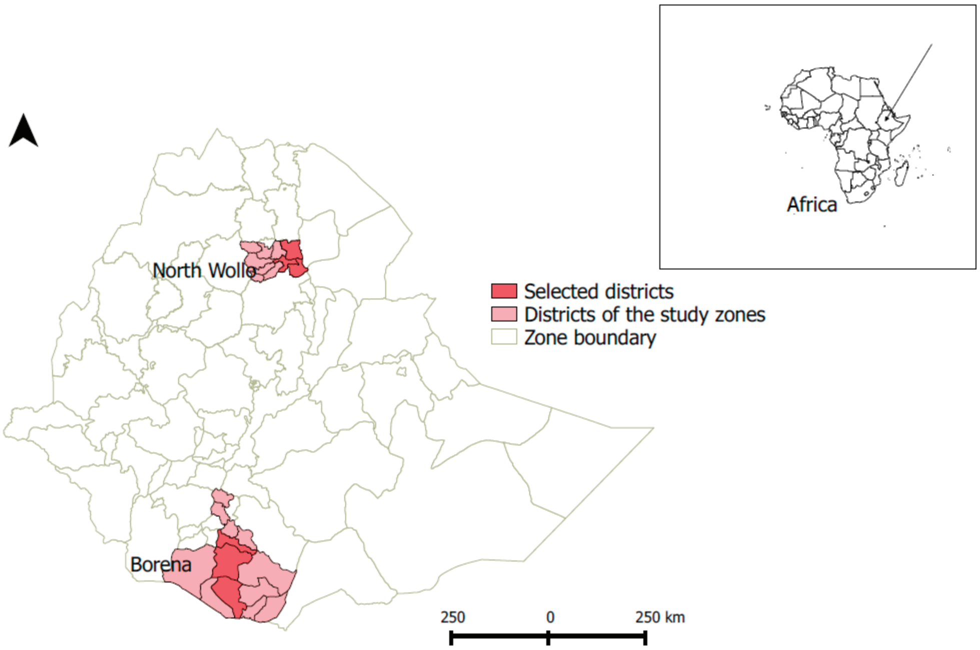

Figure 3.1. Map of Ethiopia showing the study zones and districts.

3.2.2 Sampling and data collection

The necessary sample size was determined for each zone (production system) independently. Based on the expectation of a high herd level morbidity rate (80%), a 95% confidence level and a 5% desired absolute precision, a sample size 246 small holder farmers was determined for each zone (Thrusfield, 2005). A few additional farmers were added to make up for incomplete information. Accordingly, 257 farmers from North Wollo (CLM system) and 255 farmers from Borena (pastoral system), were enrolled for the study from FMD outbreak affected kebeles[3] in the study districts. Affected kebeles were identified from the outbreak records of district veterinary offices.

3 Kebeles are administrative sub divisions of a district in Ethiopia

Sampling was done at market places, veterinary clinics and community gatherings in the study districts. Farmers were selected at some 'random' intervals from these sites (markets, veterinary clinics and meetings) and were included in the sample when they were from outbreak affected kebeles.

Data was collected using a questionnaire that was administered by interview. Before the interview, an oral consent was obtained from each participating farmer after reading a written explanation on the purpose of the study, the risks and benefits of participation in the study, the right to refuse to participate in the study as well as the conditions of confidentiality regarding the presentation of answers.

The interview was done at the end of FMD outbreaks in the respective zone by veterinarians using the structured questionnaire (Appendix 3.1). The questionnaire was designed primarily to record morbidity and mortality rates, and production losses in different categories of cattle on individual household herd level (referred simply as herd here after). Cattle were grouped into six different categories based upon their production status. These categories were 1) *lactating cows*, 2) *pregnant cows;* cows that were pregnant and not giving milk, 3) *dry cows;* cows that were neither pregnant nor giving milk, 4) *oxen;* all adult male animals that were used for plowing, 5) *young stock;* both male and female animals older than one year and not inseminated or used for plowing, and 6) *calves;* young cattle up to one year of age.

3.2.3 Estimation of morbidity and mortality rates

In the interview, farmers were asked to describe the main epidemiological and clinical features of FMD that they observed in their animals during the outbreaks. If their description was approximately consistent with the key words used in the literature description of the disease, they were considered to know the disease and the interview was continued. Then for each category of cattle, the number of animals at risk, affected, and killed by FMD was recorded to determine morbidity and mortality rates at animal and herd levels. The animal level morbidity rate was determined as the number of infected animals divided by the total number of animals at risk, and the herd level morbidity rate was determined as the number of positive herds (herds with one or more infected animals) divided by the total number of herds. Mortality rate was determined as the number of animals which died of FMD divided by the total number of animals at risk. Calves that apparently died due to a shortage of milk as a consequence of an infection in the dam were taken into account in the determination of the FMD calf mortality.

3.2.4 Estimation of economic losses

The frame work for economic impact assessment of livestock disease provided by Rushton (2009) and Kinght-Jones and Rushton (2013) as direct impacts (visible and invisible losses) and indirect impacts (additional costs and revenues foregone) was used in assessing the economic losses of the FMD outbreaks. In this study we considered the visible direct economic impact of FMD; and it was determined by an estimation of the most visible production losses such as milk loss, draft power loss and mortality loss. Because the variables used for estimation of losses were based on the responses of the individual farmers, economic loss calculations were done at herd level.

Milk loss

Milk loss due to acute FMD can arise from two situations: 1) when a lactating cow is affected and her milk yield decreases or stops during the duration of the illness and; 2) when a lactating cow dries off because of the loss of her calf. The impact of the latter situation was considered in the losses calculation due to calf mortality for expediency. Economic losses due to milk loss per FMD affected herd were calculated as

$$\mathrm{Lmilk_{ij}} = \mathrm{Ncow_i} * \mathrm{Q_i} * \mathrm{Tmilk}_i * \mathrm{Pmilk_j}$$

where $Lmilk_{ij}$ represents the economic losses due to milk loss for herd i in farming system j; $Ncow_i$ the number of lactating cows affected in herd i; Q_i the average quantity of milk lost in liters per affected cow per day in herd i; $Tmilk_i$ the average duration of illness in days of affected lactating cows in herd i, $Pmilk_j$ the price of milk per liter for farming system j.

It was difficult to determine the price of milk due to the subsistence nature of the farming systems. Whereas pastoralists sell raw milk that is extra to their household consumption at markets in nearby towns, such type of markets were nonexistent in the CLM system. In the latter case extra milk was sold only in the form of butter. In the pastoral system a seasonal average milk price of USD[4] 0.66/liter was determined from a survey of four small town markets (Finchewa, Surpha, Bekie, Dubluk) in the study districts. In the CLM system a proxy price of USD 0.49/liter was used based on the milk price obtained by the market oriented farmers in the surrounding urban centers (Woldya and Kobo towns).

4 Prices were originally collected in Birr (Ethiopian currency) and converted into USD using the study period's average exchange rate of 0.0547 USD/Birr.

Draft power loss

The losses associated with a reduction in available draft power were calculated only for the CLM system as draft power was not commonly used in the pastoral system. Economic losses due to draft loss per herd equaled

$$\mathrm{Ldraft_i} = \mathrm{Noxen_i} * (\mathrm{Tdraft_i} * \mathrm{adj}) * \mathrm{Pdraft}$$

where $Ldraft_i$ represents the economic loss due to draft power loss for herd *i*; $Noxen_i$ the number oxen affected in herd *i*, $Tdraft_i$ the average duration of illness in days of an affected ox in herd *i*, *adj* an adjustment factor, and *Pdraft* the price of draft power rent of an ox per day.

Draft power for crop production (plowing and threshing) is not needed throughout the year because of seasonality in crop production. Moreover not all days in the planting season are effective working days. According to Goe (1987) draft oxen in smallholder farms of Ethiopia work only for about 65 days a year. The probability that a day on which an ox is ill coincides with an effective working day equals, therefore, to 65/365 (0.178). This ratio is used as an adjustment factor (adj) to change the days of illness to actual working days lost. There was no market for draft power rent except in some peri-urban localities. In most cases farmers whose oxen are unable to work borrow oxen from their relatives to work their land. The rent price of an ox of USD 2.74/day as quoted in peri-urban areas was used to estimate the costs related to the draft loss.

Mortality loss

The losses due to mortality equaled the market price of the animal that died. Therefore, the economic loss due to mortality per herd was calculated as

$$\begin{aligned}\mathrm{Lmort_{ij}} = {} & (\mathrm{Nmortcalf_i} * (\mathrm{Pcalf} + (1/3\ \text{average milk yield per lactation} * \mathrm{Pmilk_j}))) \\ & + (\mathrm{Nmortyoung_i} * \mathrm{Pyoung}) + (\mathrm{Nmortadult_i} * \mathrm{Padult})\end{aligned}$$

where $Lmort_{ij}$ represents the economic losses due to mortality for a herd *i* in farming system *j*; $Nmortcalf_i$ is the number of calves died in herd *i; Pcalf* is the price of a calf; $Pmilk_j$ is price of milk per liter in framing system *j*; $Nmortyoung_i$ is the number of young stock died in herd *i*; Pyoung is the price of a head of young stock, $Nmortadult_i$ is the number of adult cattle died in herd *i*, and *Padult* is the price of an adult head of cattle. When a calf dies, the dam stops lactating for the rest of the lactation period. The economic loss due to a calf death is, therefore, based on the value of the calf as well as the value of the milk lost due to early drying off the dam. As calf deaths did not always occur at the beginning of lactation only one third of the lactation yield is assumed to be lost due to calf death. The total lactation yield of local cows as estimated from several studies in rural areas of Ethiopia is on average 448 liter (Behnke, 2010). The average prices of USD 164.10 and USD 273.50 respectively per young and adult animal (cows and oxen), were derived from the farmers response in both farming systems. No price for calves was quoted by the farmers and a price of USD 27.35 was estimated by the authors.

Total economic losses

The total economic losses per individual herd were aggregated as the sum of all losses arising from milk loss, draft loss and mortality:

$$\mathrm{TEL}_{ij} = \mathrm{Milk}_{ij} + Draft_i + Mort_{ij}$$

where TEL_{ij} represents the total economic losses for herd i in farming system j, $Milk_{ij}$ the economic losses due to milk loss in herd i in farming system j, $Draft_i$ the economic losses due to draft loss for herd i; and $Mort_{ij}$ the economic losses due to mortality in herd i in farming sytem j.

The average economic loss per individual head of cattle present in the affected herds was determined by dividing the total economic losses in the herd by the total number of cattle in the herd.

3.2.5 Statistical analysis

Statistical analyses were conducted to test the significance of differences in herd level FMD morbidity rates and economic losses between farming systems and between districts within the farming systems. A Chi-square test was used to evaluate the differences in herd level morbidity rates between farming systems and districts; and Fisher's exact test was used for those comparisons where the expected counts of cells in the contingency tables were less than five. An independent samples *t*-test was used to evaluate differences in herd level economic losses between farming systems; and a one-way ANOVA to test the differences between districts within the farming systems. A least significant difference test was conducted for multiple comparisons of means when they appeared significant in the one-way ANOVA test. The data on the herd level economic losses were log transformed to correct for the skewness observed in the original data. All statistical analyses were performed using IBM SPSS statistical package (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp).

3.3 Results

3.3.1 Cattle herd size and structure

A total of 512 smallholder farmers were surveyed in the six districts that represent the crop livestock mixed (CLM) and pastoral farming systems. The herd size and structure for both farming systems are presented in Table 3.1. The mean household cattle herd size in the pastoral system (36 heads of cattle per herd) was higher than in the CLM system (7 heads of cattle per herd). Cattle herd sizes were variable and skewed to the right. Whereas oxen represented the highest percentage of the herd in CLM system, lactating cows and calves represented the highest percentage in the pastoral system.

Table 3.1. Cattle herd size and structure per farming system

		Farming system	
		CLM	**Pastoral**
Number of herds		257	255
Herd size			
	Mean	7	36
	percentiles (5^{th}, 50^{th}, $95^{th)}$	2, 6, 16	9, 28, 95
Cattle category (%)			
	Lactating cow	18.87	22.22
	Pregnant cow	8.97	14.01
	Dry cow	7.04	10.22
	Oxen	27.02	11.28
	Young stock	20.17	20.27
	Calf	17.93	22.00

3.3.2 Morbidity and mortality

Several outbreaks of FMD were reported in the study areas during the period of 2012-2013. The outbreaks were confirmed and the causal virus identified as serotype O by antigen detection ELISA at the national animal health diagnostic and investigation center (Sebeta, Ethiopia). All the farmers surveyed were able to describe the disease in terms of its key symptoms and epidemiologic features. The pastoral districts were more widely affected by outbreaks in terms of affected kebeles (78.2%) and herds (94.9%) than the districts in the CLM in which 49.0% of the kebeles and 85.2% of the herds were affected (Table 3.2). However, animal level morbidities and mortalities in the affected herds were higher for the CLM system (Table 3.3). Herd level morbidity rates were significantly higher in the pastoral system than in the CLM system ($p < 0.001$). Further analysis of differences of herd level morbidity rates between districts within each farming system showed no statistically significant differences ($p > 0.05$) (Table 3.2).

Table 3.2. FMD infection rates at kebele and herd level per farming system and district

Farming system	District	No. of kebeles	Kebeles affected (%)	No. of herds surveyed	Herds affected (%)*
CLM	Kobo	40	82.5	80	88.8
	Guba Lafto	32	21.9	75	78.7
	Habru	30	33.3	102	87.3
	Overall	**102**	**49.0**	**257**	**85.2****
Pastoral	Dugda Dawa	16	81.3	81	98.8
	Dire	16	100	80	93.8
	Yabello	23	60.9	94	92.6
	Overall	**55**	**78.2**	**255**	**94.9*****

* χ^2 (1) = 13.4, p = 0.000 for differences in herd level morbidity between farming systems;** χ^2(2) = 3.68, p = 0.159 for differences in herd level morbidity between CLM districts;*** Fishers exact p = 0.122 for differences in herd level morbidity between pastoral districts.

Based on farmers' diagnosis, the animal level morbidity and mortality rates due to FMD outbreaks in the affected herds were, respectively, 74.3% and 2.4% in the CLM system and 60.8% and 0.7% in the pastoral system (Table 3.3). Morbidity and mortality rates in different categories of cattle in the affected herds are presented in Table 3.4. High morbidity was observed in lactating cows and oxen in the CLM system with the similar pattern in all districts. No specific pattern of morbidity in the cattle categories was observed in the pastoral system. Adult mortality was generally low. Relatively higher mortality rates were observed in calves, viz. 9.7% for CLM and 2.6% for pastoral system (Table 3.4). Animal level morbidity rates in the affected herds range from 13% to 100% CLM system and from 7% to 100% in the pastoral system.

Table 3.3. FMD morbidity and mortality rates in affected herds per farming system and district

Farming system	District	No. of herds	No. of cattle	Morbidity (%)	Mortality (%)
CLM	Kobo	71	713	78.4	3.2
	Guba Lafto	59	231	67.1	2.2
	Habru	89	662	71.8	1.5
	Overall	**219**	**1,606**	**74.3**	**2.4**
Pastoral	Dugda Dawa	80	2,882	61.0	0.4
	Dire	75	2,994	62.2	0.6
	Yabello	87	2,726	59.2	1.0
	Overall	**242**	**8,602**	**60.8**	**0.7**

Table 3.4. FMD morbidity and mortality rates in different categories of cattle in the affected herds per farming system

Farming system	Category of cattle	No. of cattle	Morbidity (%)	Mortality (%)
CLM	Lactating cow	303	83.8	0.3
	Pregnant cow	144	75.7	0.0
	Dry cow	113	70.8	0.0
	Oxen	434	85.7	0.7
	Young stock	324	71.0	1.9
	Calf	288	50.0	9.7
Pastoral	Lactating cow	1,912	63.9	0.2
	Pregnant cow	1,204	57.8	0.2
	Dry cow	879	68.2	0.3
	Oxen	970	63.5	0.3
	Young stock	1,744	60.2	0.1
	Calf	1,893	55.5	2.6

3.3.3 Economic losses

Economic losses from milk reduction, draft power loss, and mortality per affected individual animal are presented in Tables 3.5, 3.6 and 3.7, respectively. The mean daily milk loss per cow was 1.8 liters (ranging 0-4 liters) and 1.8 liters (ranging 0.5-3 liters) for the CLM and pastoral system, respectively. The losses were roughly the same in the two systems and were on average more than 75% of the daily milk yield. The mean duration of illness in cows that led to milk reduction was 33.6 days (ranging 7 to 90 days) for the CLM system and 23 days (ranging 7-35 days) for the pastoral system. The mean number of effective working days lost by an affected ox was 5 days (ranging 1-15 days). The highest mean economic loss at the individual affected animal level was due to mortality (Table 3.7) which was on average USD 129 per animal died in the CLM and USD 151 per animal died in the pastoral system, followed by the losses resulting from milk reduction which was on an average USD 29 and USD 26 per affected cow in the CLM and the pastoral systems, respectively (Table 3.5).

Table 3. 5. Economic losses due to milk loss per FMD affected lactating cow per district and farming system

Farming system	District	Daily milk yield (liters)	Daily milk loss due to FMD (liters)	Duration of FMD illness (days)	Quantity of milk lost (liters)	Economic losses (USD)
		mean (range)	mean (range)	mean (range)	mean (range)	mean (range)
CLM	Kobo	2.3 (1-5)	1.8 (1-4)	40 (7-90)	72 (7-360)	35 (3-176)
	Guba Lafto	2.5 (1-3)	1.6(0-2.3)	35 (14-60)	56 (0-138)	27 (0-68)
	Habru	2.3 (1-4)	1.8 (1-4)	25 (7-60)	45 (7-360)	22 (3-176)
	Overall	**2.3 (1-4)**	**1.8 (0-4)**	**33 (7-90)**	**59.4 (0-360)**	**29 (0-176)**
Pastoral	Dugda Dawa	2.1 (0.7-4)	1.6 (0.7-3)	23 (10-35)	37 (7-105)	24 (5-69)
	Dire	2.3 (1-4)	1.8 (1-3)	21 (7-30)	38 (7-90)	24 (5-59)
	Yabello	2.2 (0.5-4)	1.8 (0.5-3)	26 (10-30)	47 (5-90)	31(5-59)
	Overall	**2.2 (0.5-4)**	**1.8 (0.5-3)**	**23 (7-35)**	**41 (3.5 -105)**	**26(5-69)**

Table 3.6. Economic losses due to draft power loss per affected ox in CLM district

Districts	Duration of FMD illness (days)	Effective working hours lost*	Economic loss (USD)
	mean (range)	mean (range)	mean (range)
Kobo	37 (14-84)	7 (2-15)	18 (7-41)
Guba Lafto	28 (7-56)	5 (1-10)	13 (3-27)
Habru	25 (7-56)	5 (1-10)	12 (3-27)
Overall	**30 (7-84)**	**5 (1-15)**	**15 (3-41)**

*An adjustment factor of 0.178 was used to change duration of illness into effective working days lost.

Table 3.7. Economic losses due to mortality per head of cattle per district and per farming system

Farming system	District	No. of adult cattle died	No. of young stock died	No. of calves died	Average economic loss per animal died (USD)
CLM	Kobo	4	6	13	148
	Guba Lafto	0	0	5	101
	Habru	0	0	10	101
	Overall	**4**	**6**	**28**	**129**
Pastoral	Dugda dawa	3	1	11	160
	Dire	1	0	18	134
	Yabello	6	0	20	160
	Overall	**10**	**1**	**49**	**151**

The mean total economic losses of FMD outbreak at herd level were USD 76 (5^{th} - 95^{th} percentiles: USD 7-271) for the CLM system and USD 174 (5^{th} - 95^{th} percentiles: USD 10-648) for the pastoral system. These herd level losses were variable and highly skewed to the right in both farming systems (Table 3.8). The mean total herd level economic losses in the CLM system were statistically significantly lower than in the pastoral system ($p < 0.001$). Comparison of mean total herd level losses between districts within each farming system using a one-way ANOVA showed a statistically significant difference between the CLM districts ($P < 0.001$) but not in the pastoral districts ($P > 0.05$). *Post hoc* comparison of districts in the CLM system using the least significant difference technique revealed significant differences between all pairs of districts with the losses being highest in Kobo and lowest in Guba Lafto districts. At herd level, the largest component of the economic loss was due to milk loss, and in CLM system it was followed by draft loss. Mortality was the least contributor of herd level losses in both systems (Table 3.8).

The average economic losses per animal present in an affected herd were USD 9.8 in CLM system and USD 5.3 in the pastoral system.

Table 3.8. Economic losses of FMD per herd per district and farming system in USD indicated by mean and percentiles

Farming system	Districts	Milk losses	Draft losses	Mortality losses	Total economic losses[*]
		mean (5th, 50th, 95th)	mean (5th, 50th, 95th)	mean (5th, 50th, 95th)	mean (5th, 50th, 95th)
CLM	Kobo	56 (0,44,212)	36 (0,27,82)	48 (0,0,285)	140 (20,89,47)
	Guba Lafto	2 (0,0,5)	19 (0,14,55)	9 (0,0,101)	29 (0,14,128)
	Habru	23 (0,15,88)	21 (0,14,55)	11 (0,0,101)	55 (0,34,176)
	Overall	**28 (0,7,123)**	**25 (0,27,55)**	**22 (0,0,164)**	**76 (7,35,271)**[**]
Pastoral	Dugda dawa	128 (0, 89, 394)	-	33 (0,0,273)	161 (0,116,613)
	Dire	136 (17,87,576)	-	33 (0,0,256)	169 (17,94,749)
	Yabello	143 (0,109,426)	-	48 (0,0,391)	190 (0,119,706)
	Overall	**136 (9,97,415)**	**-**	**39 (0,0,274)**	**174 (10,110,648)**[***]

[*]t (459) = -7.05, p < 0.000 for differences in total economic losses between farming systems; [**]F (2, 216) = 35.85 P < 0.000 for differences in total economic losses between CLM districts; [***]F (2, 239) = 0.57, P = 0.564 for differences in total losses between pastoral districts.

3.4 Discussion

The mean cattle herd sizes recorded in this study (7 heads for crop-livestock mixed (CLM) and 36 heads for pastoral) were higher than the national averages reported previously for the respective systems (4 heads for CLM and 13 heads for pastoral) (Negassa and Jabbar, 2008). One explanation for these differences could be the fact that in the present study only those farmers who owned cattle were included, where as in the national estimates cattle herd sizes were averaged over all smallholders keeping livestock, independent of whether they owned cattle or not. Negassa and Jabbar (2008) reported that only 83% farmers in the CLM system and 78% of the famers in the pastoral system owned cattle.

Draft oxen constitute the highest proportion of cattle in the herds within the CLM system and their proportion increases with decreasing herd size. This indicates the priority given to oxen by farmers, emphasizing the importance of cattle as source of draft power in this type of farming system. This corresponds to the general objective of cattle raising in the CLM farming system where cattle are primarily kept for provision of draft power and other inputs for crop production (Negassa et al., 2011). The highest proportion of cattle in the pastoral systems represents lactating cows on which the pastoral households depend on for food subsistence.

A high morbidity of FMD was reported both at herd level (85% for CLM system and 95% for pastoral systems) and animal level (74% for CLM and 61% for pastoral). The herd level morbidity rate was statistically higher in the pastoral herds as compared to CLM herds but the differences in morbidity rates between districts within each farming system were not statistically significant. This indicates the importance of the farming system in the epidemiology of the disease. The difference might be due to the high contact rates among household herds in the pastoral farming system that is related to their mobility.

Comparable animal level morbidity rates ranging between 60-100% were reported previously in the CLM system in eastern parts of Ethiopia (Mersie et al., 1992, Roeder et al., 1994). The mortality rates of 2.4% in the CLM system and 0.7% in the pastoral system are generally low and in line with common knowledge that FMD is characterized by low mortality in adult animals (OIE, 2009). A higher morbidity was seen in oxen and lactating cows, the producing members of the herds, than the other categories of cattle in the CLM system. This could be associated with production stress and/or high contact with humans during milking and plowing, which might facilitate transmission of infection among these groups of animals. During FMD outbreak oxen from non-infected herds often moved to infected areas to assist in plowing lands of farmers whose oxen are affected. This may result in a wider dissemination of an outbreak. This indicates the importance of special emphasis on oxen in control efforts like vaccination to reduce both farmers' loss of draft power at critical time of planting, and the disease spread in the cattle population in the CLM farming system.

Assessment of economic losses due to the outbreaks indicated that the largest losses at the animal level obviously occurs when the animal dies. Mortality losses were on average USD 129 per animal died in the CLM system and USD 151 per animal died in the pastoral system. The differences are merely a reflection of the difference in number of mortality cases per category of animals in which death of more adult animals means higher losses. The second largest losses at animal level were due to milk loss, representing USD 29 per affected lactating cow for the CLM system and USD 26 per affected lactating cow for the pastoral system. These losses vary wildly as indicated by the ranges in Tables 3.5 and 3.6. For example the economic losses due to milk loss in the CLM varied from nil to USD 176 per affected lactating cow depending on the yield level of the cow, the severity of milk reduction and the duration of the illness. In this study it was assumed that milk yield returned to pre-clinical FMD levels after the clinical recovery of the cows. There is, however, an indication that milk yield may not return to normal after clinical recovery. A study in dairy farms in Pakistan reported a milk yield reduction of up to 30% two months after infection compared to the pre-clinical FMD yield (Ferrari et al., 2013). Nevertheless, as management and physiological (e.g., lactation stage) factors were not controlled, it is difficult to account the remaining yield reduction primarily as an effect of the disease. We, therefore, chose to remain cautionary with our calculations and assumed a return of the milk production to pre-clinical levels so that we did not overestimate the losses due to FMD.

At herd level the most important losses arise from milk loss followed by draft loss in case of the CLM system. Mortality losses are relatively low. The importance of milk and draft losses in the economic impact estimate is consistent with the primary objectives of keeping cattle in the smallholder subsistence systems, which are aimed at the production of subsistence milk and traction power for the pastoral and CLM system, respectively. The mean total economic losses per herd of USD 76 for the CLM system was statistically significantly lower than the average mean loss of USD 174 for the pastoral system. The higher losses per herd in the pastoral system could mainly be explained by its larger herd sizes. The herd level losses were variable and highly skewed to the right in both farming systems. This was the result of high losses in a few herds which had mortality cases, and the skewed distribution of the herd sizes.

The quantitative assessment of the direct economic impact of FMD in this study did not include all conceivable impacts of the disease. Only those losses that are of crucial importance to the farming systems under study and that were relatively easy to quantify were considered. As such the economic losses estimated should be seen as a conservative estimate of the potential losses. Besides the evaluated losses, loss of condition could be an important FMD impact as well. Some studies in similar smallholder settings in other countries used the loss of condition as the main basis for the estimation of the economic impact of the disease (Rast et al., 2010; Young et al., 2013). Subsistence smallholder farmers in Ethiopia have, however, low market off-take rates and low market participation level (Negassa and Jabbar 2008). They sell animals only at times of an acute cash shortage like during a bad crop harvest and drought. So the impact of FMD in terms of condition loss will only be significant at such selling occasions. In normal times, condition loss will be regained slowly after recovery and its impact will not be that high. The impacts of the disease related to poor growth and reproduction performance occur in very subtle way and may halve long term effects in the herd dynamics and, therefore, need not to be overlooked in the decision making about the control of the disease. In addition to the production impacts, we have attempted to include costs related to the treatment of sick animals and the disposal of dead animals during the outbreaks. Expenditures on modern treatment of sick animals were, however, made only by a few farmers in the pastoral system. Most farmers used traditional practices to treat sick animals which were difficult to translate into a monetary value. Dead animals were disposed in the open field for scavengers; farmers, therefore, did not experience any disposal costs.

Even for the visible direct FMD impacts quantified in this study, it was difficult and probably improper to convert the impacts into financial loss. As the farming systems are not market oriented, the impact on the goods and services of cattle affected by the disease have in most cases no direct cash effect. The milk produced in these systems is used for own family consumption. The actual loss of milk is, therefore, not reflected in terms of cash income alone but also has negative effect in the food security and nutrition of the family, especially in essential micronutrients in milk diet that are crucial for children health and growth. Similarly the draft power loss is reflected as a reduction in the productivity of crop production rather than an immediate financial loss. The loss estimated here can be, therefore, considered as a proxy quantitative measure that is used to uncover the disease's otherwise covert impacts on the farmers' welfare.

The estimated losses due to the disease outbreak represent a significant burden for the affected households. For example, the losses of USD 76 per household in the CLM system constitutes about 6.8% of the total annual expenditure (a proxy of income) of an average household in this system which is estimated to be about USD 1,122 (CSA, 2012). Taking a loss of more than 10% of income as a bench mark for a catastrophic shock (Shanker et al. 2012), the 6.8% loss of income for CLM households is a significant burden. This percentage obviously would be much higher and the consequences more sever for pastoral households because of their total dependency on livestock for their livelihood.

To the best knowledge of the authors no quantitative assessment of production losses has been previously reported for smallholder farmers in Ethiopia for comparison. Similar studies in countries of South and Southeast Asia where cattle and buffalo are extensively used in smallholder rice-livestock production have reported a much higher loss due to FMD (Rast et al, 2010, Shanker et al., 2012; young et al., 2013). However these economic loss estimates vary widely among the reports. For example a loss of USD 52.4 per affected head of cattle was reported form Laos (Rast et al, 2010) while this reached USD 216.32-370.54 per affected cattle in Southern Cambodia (Young et al., 2013). Even in the same country Cambodia, widely variable estimates are reported like USD 45 per affected household by Shanker et al. (2012) and USD 216.32-370.54 per affected cattle by Young et al. (2012). These differences, in addition to the intrinsic variations of outbreaks used for the case studies that affect some of the parameters (e.g. duration illness, level of production loss etc.), are also results of differences in the range and type of losses and /or costs quantified, as well as the prices. This wide variation in estimation of FMD losses may be a problem in evaluating the cost benefit ratio of control interventions and calls for a standard methodological framework for estimating the impact in smallholder farming system in developing countries where cattle are used for multiple functions.

This study excluded the indirect effects of the disease like its effect on international trade, costs of surveillance and the disease's impact on other species like small ruminants, all of which are important in Ethiopia. These factors, added to more subtle direct effects that were not quantified (like long term effect on herd structure), make the loss of the disease much more substantial than the one estimated in this study. This demonstrates a potential economic gain from a control intervention against the disease in these livestock systems. For example, the estimated losses of USD10 for the CLM system, and USD 5 in the pastoral system per animal indicate that a biannual vaccination with a cost of two USD per vaccination could be economically profitable, if the vaccine is fully effective and the risk of FMD is at least once every 5 years for the CLM system and 2.5 years for pastoral system. It must be noted, however, that the impact of the disease, as mentioned elsewhere in this report, did not occur directly as financial loss and its main impact would be on the social wellbeing of the farmers in terms of food security and nutrition. In some situations, the disease's impact even goes beyond the economic domain. For example, in Borena pastoral area it was reported that cattle affected by FMD cannot be used for dowry which is one the basic functions of cattle in that area (Jibat et al., 2013). Generally the decision related to intervention against the disease is complex and needs consideration of all facets of the disease's impact.

3.5 Conclusions

Foot and mouth outbreak in the cattle population of smallholder farmers causes high morbidity and associated economic losses that represent significant part of smallholders' income. The losses are variable among households and are higher for pastoral households than for households within the crop-livestock mixed system. Although the presented estimates on the economic losses accounted for only the visible direct impacts of the disease on herd level, these conservative results already signify a potential socioeconomic gain from a control intervention given the current frequency of FMD outbreak in the country. Formal and comprehensive evaluation of all costs and benefits of the disease and potential control options is, however, required before a recommendation for control intervention.

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Appendix 3.1

FMD outbreak impact assessment questionnaire

(Translated from Amharic to English)

1. Name of the herd owner (optional) _______________
2. Herd location:
   village______________________
   kebele _____________________
   district _____________________
3. Have your ever heard of FMD? Yes /No
   If yes, can you describe its clinical signs (Continue with questionnaire if one or more of the following signs are described)
   i. Lameness due to foot lesions and salivation due to mouth lesions in cattle and/ or small ruminants.
   ii. Foot lesions in cattle and/ or small ruminants that is contagious.
   iii. Mouth lesions in cattle and/ or small ruminants that is contagious.
   iv. Lameness or mouth lesions, and blisters (sores)on teats of cows
4. Did the recent FMD outbreak affect your herd? Yes/No.
5. If yes, can you indicate the period at which the outbreak occurred?
   started ________________
   ended ________________
6. Morbidity and associated consequences of a FMD outbreak per category of cattle within the herd.

Category	Total no. present	No. affected by FMD	Average duration (weeks)	No. aborted	No. died	Average treatment cost (Birr)
Lactating cows						
Pregnant cows						
Dry cows						
Draft oxen						
Young stocks						
Calves						

8. Average daily milk production before the onset of outbreak ----------(liter/day)
9. Average daily milk yield production during the FMD illness period ----- (liter/day)
10. How long did the affected lactating cows produce less? -----------
11. How long did the affected oxen stay out of work during the illness -------
11. What did you do with animals that died of FMD? Meat consumed or thrown away? If thrown away, what were the costs for disposal? --------

Chapter 4

Farmers' Intentions to Implement Foot and Mouth Disease Control Measures in Ethiopia

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Abstract

The objectives of this study were to explore farmers' intentions to implement foot and mouth disease (FMD) control in Ethiopia, and to identify perceptions about the disease and its control measures that influence these intentions using the Health Belief Model (HBM) framework. Data were collected using questionnaires from 293 farmers in three different production systems. The influence of perceptions on the intentions to implement control measures were analyzed using binary logistic regression. The effect of socio-demographic and husbandry variables on perceptions that were found to significantly influence the intentions were analyzed using ordinal logistic regression. Almost all farmers (99%) intended to implement FMD vaccination free of charge. The majority of farmers in the pastoral (94%) and market oriented (92%) systems also had the intention to implement vaccination with charge but only 42% of the crop-livestock mixed farmers had the intention to do so. Only 2% of pastoral and 18% of crop-livestock mixed farmers had the intention to implement herd isolation and animal movement restriction continuously. These proportions increased to 11% for pastoral and 50% for crop-livestock mixed farmers when the measure is applied only during an outbreak. The majority of farmers in the market oriented system (>80%) had the intention to implement herd isolation and animal movement restriction measure, both continuously and during an outbreak. Among the HBM perception constructs, perceived barrier was found to be the only significant predictor of the intention to implement vaccination. Perceived susceptibility, perceived benefit and perceived barrier were the significant predictors of the intention for herd isolation and animal movement restriction measure. In turn, the predicting perceived barrier on vaccination control varied significantly with the production system and the age of farmers. The significant HBM perception predictors on herd isolation and animal movement restriction control were significantly influenced only by the type of production system. The results of this study indicate that farmers' intentions to apply FMD control measures are variable among production systems, an insight which is relevant in the development of future control programs. Promotion programs aimed at increasing farmers' motivation to participate in FMD control by charged vaccination or animal movement restriction should give attention to the perceived barriers influencing the intentions to apply these measures.

Key words: disease control, Ethiopia, foot and mouth disease, Health Belief Model, intention, perception

4.1 Introduction

Ethiopia has the largest cattle population in Africa with 54 million heads of cattle (CSA, 2013). Within the cattle population, foot and mouth disease (FMD) occurs endemically resulting in several outbreaks a year (Ayelet et al., 2012). These outbreaks affect a large part of the country (Jemberu et al., 2015) causing significant economic losses in the affected herds (Jemberu et al., 2014). The Ethiopian government is keen in to launching an official control program against FMD to reduce production losses and to improve the export trade of animals and animal products (Thomson, 2014).

Successful livestock disease control programs, for example through mass vaccination, depend not only on technical and economic feasibilities, but also on the motivation of the farming community to fully participate in the implementation of the control program (Roeder and Taylor, 2007). Farmers' motivation to implement a specific disease control measure is largely driven by their perceptions of the disease's risk and the effectiveness of available control measures(Delabbio et al., 2005; Garforth et al., 2013). Perceptions about the effectiveness of farming technologies, including that of livestock disease control, are known to be important predictors of the eventual technology uptake (Adesina and Baidu-Forson, 1995; Fandamu et al., 2006).

Farmers' adoption of a specific livestock disease control measure or participation in national animal disease control programs involves a behavioral change in the farming practice. In order to achieve behavioral change, insight in the cognitive factors (perceptions) driving the behavior is important. Health behavioral models are often used to study perceptions that influence health related behaviors in public health (Glanz et al., 2008). Health behavioral models are also being used more and more in animal health research in recent times to study farmers' behavior with regard to disease control and prevention on their farms (Alarcon et al., 2014; Bruijnis et al., 2013; Delgado et al., 2014; Ellis-iversen et al., 2010; Valeeva et al., 2011).

Health belief model (HBM) is one of the most commonly used individual health behavioral models in public health (Champion and Skinner, 2008; Glanz and Bishop, 2010). The core concept behind the HBM is that health behavior is determined by the personal beliefs or perceptions about the disease's risk and available control measures (Champion and Skinner, 2008). The model has been developed to evaluate perceptions influencing preventive health behaviours (actions undertaken by an individual who believes himself (or herself) to be healthy, for the purpose of preventing or detecting illness in an asymptomatic state) (Janz and Becker, 1984). The basic concept of the HBM also applies to farmers' behavior related to animal disease prevention in their farms; and has been used to study the factors underlying farmers' adoption of animal disease prevention and control measures (Valeeva et al., 2011).

In Ethiopia, there are three types of cattle production systems, viz. crop-livestock mixed (CLM), pastoral and market oriented systems (MoARD, 2007). Due to differences in the epidemiology and economic impacts of FMD in these production systems (Jemberu et al., 2015, 2014), cattle farmers could have different perceptions about the disease risk and, therefore, different intentions towards the uptake of control measures. Understanding farmers' perceptions of FMD and its control in the different production systems and their intentions to apply control measures is, therefore, important in designing a national FMD control promotion program that insures the comprehensive participation of all cattle farmers. Currently this understanding is seriously lacking.

The objectives of this study were, therefore, to explore livestock farmers' intentions to implement FMD control measures in the different cattle production systems of Ethiopia, and to identify perceptions about the disease and its control measures that influence the intentions to implement control measures using the HBM framework.

4.2 Materials and Methods

4.2.1 Theoretical framework

The basic concept of HBM is that health behavior is determined by personal beliefs or perceptions about the disease risk and control measures available to decrease its occurrence (Champion and Skinner, 2008). The HBM outlines four basic perception constructs that influence the resulting health behavior. These constructs include:

1. perceived *susceptibility* or belief about the likelihood of getting a disease or condition,
2. perceived *severity* or belief about how serious a condition and its sequelae are,
3. perceived *benefits* or belief in efficacy of the advised action to reduce threat i.e. susceptibility and severity, and
4. perceived *barriers* or belief about the tangible or intangible costs of the advised action.

These perceptions, individually or in combination, explain adoption or non-adoption of a particular health behavior. If individuals believe that they are susceptible to a disease, believe that the disease would have a serious consequences, believe that a prevention measure available to them would be beneficial in reducing their susceptibility to or severity of the disease, or believe the expected benefits outweighs the cost of the available measure, then they are likely to apply the measure. Through time, additional constructs have been added to the model such as self-efficacy (confidence in one's ability to take action) and cue to action (strategies to activate "readiness") along with modifying variables (demographic and socio-psychological variables that have an indirect effect on behavior by influencing the perception of susceptibility, severity, benefits, and barriers) (Champion and Skinner, 2008).

In the present study, the four basic constructs of the HBM were used to assess farmers' perceptions of FMD and its control in Ethiopia. In the evaluation of the effect of these perceptions on the motivation of farmers to implement control measures against the disease, the *intention* to participate in hypothetical FMD control measures was considered as a proxy of the actual behavior. This is due to absence of any official control in practice to measure the behavior directly. Although intention does not always translate to behavior, it is known to be the immediate and the strongest predictor of behavior (Sheeran, 2002). In the analysis, socio-demographics and husbandry variables were used as modifying factors of the perception constructs. The theoretical framework as adapted from Champion and Skinner (2008) is presented in Figure 4.1.

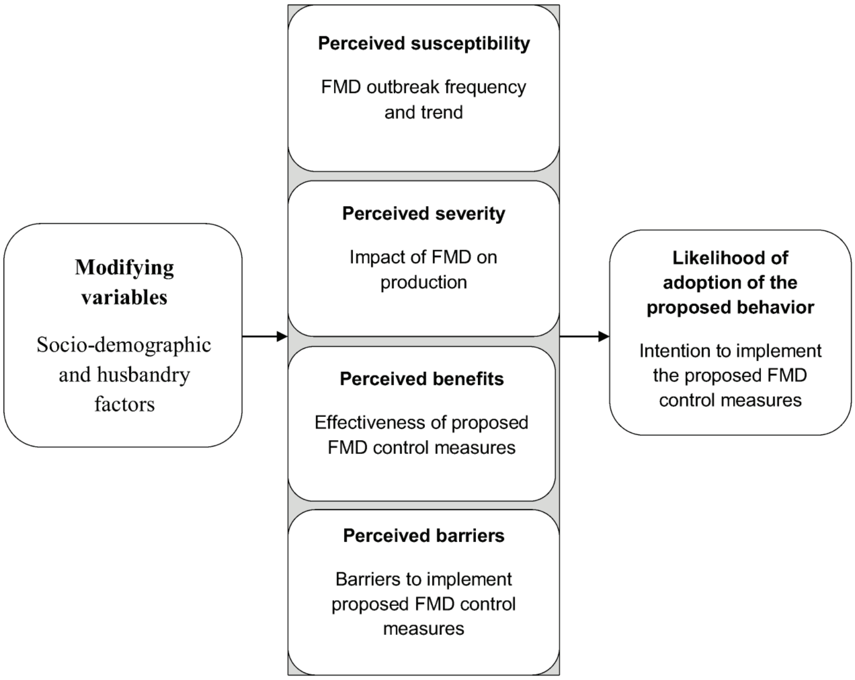

Figure 4.1. The constructs of the Health Belief Model as applied in the performed analyses on the intention to implement FMD control measures (adapted from Champion and Skinner (2008)).

4.2.2 Questionnaire design

A questionnaire was designed based on the framework described above. Each model construct was measured using a set of rating scale items (questions).

The perceived *susceptibility* of farmers to the disease risk was elicited by three rating questions. The first question assessed the frequency of FMD outbreaks as experienced in farmers' own herd. The second question referred to the experienced frequency in the kebele herd (kebele is the smallest administrative level in Ethiopia). Both questions were answered on a four point rating scale, which indicated the frequency of having an outbreak every 1, 2, 5 or 10 years. In the statistical analysis, this scale was converted into a three points qualitative scale reflecting "high" (corresponding to every year), "medium" (corresponding to every 2 years) and "low" (corresponding to every 5 and 10 years) frequency. The third question measured the perceived trend of FMD occurrence by a three points rating scale (decreasing, unchanging, increasing).

The perceived *severity* was measured using two rating questions on a three points scale (high, medium, and low): one question was about the impact of FMD relative to general livestock production problems and the other question about the impact of FMD relative to the impact of other livestock diseases.

The perceived *benefits* (effectiveness) of potential FMD control measures were measured by two rating scale questions on a three points scale (high, medium, low) for proposed control measures related to vaccination, and herd isolation (avoiding mixing cattle of different household herds) and animal movement restriction.

The perceived *barriers* to the proposed control measures were measured by four rating scale questions on a three points scale (high, medium, low). The four questions referred to the difficulty of paying the costs of vaccination (estimated costs of 40birr[5]/animal/per year for biannual vaccination using trivalent vaccine), problem of side effects of vaccination (unwanted effect of the vaccination on animal health), difficulty of trekking and handling animals for vaccination, and the difficulty of herd isolation and animal movement restriction.

The *intentions* were assessed for four proposed specific FMD control measures, including 1) vaccination of cattle two times a year using trivalent vaccine with charge (covering the estimated annual costs of 40 birr per animal) 2) vaccination of cattle two times a year using trivalent vaccine free of charge, 3) herd isolation and animal movement restrictions as a continuous measure (irrespective of the presence or absence of active FMD outbreak) and 4) herd isolation and animal movement restriction only during an outbreak of FMD. Farmers were asked about their intentions to implement these FMD control measures by using yes or no questions.

5 Birr is Ethiopian currency and at the time of the study 1 birr = 0.05 USD

Socio-demographic variables of farmers such as gender, age and education status, and husbandry variables such as production system, cattle herd size and contribution of livestock to livelihood as well as knowledge of FMD and experience with the disease within own herd were documented using open ended questions.

A pilot survey was tested on 10 farmers and based on the results of this pilot, the questionnaire was adjusted to increase operationalization. The main adjustment consisted of a reduction in the size of the response scale from originally five to three points for the practical reasons of minimizing confusion of farmers and increasing the validity of the rating of the farmers.

4.2.3 Data collection

4.2.3.1 Cattle production systems

In Ethiopia, the dominant production system is the crop-livestock mixed (CLM) system that prevails in the central highland parts of the country and accounts for about 80-85% of the cattle population and 40% of the land area (MoARD, 2007). In this system, cattle are owned by sedentary farmers who mainly grow crops. Cattle are primarily used for draft power in crop cultivation. The second most dominant farming system is the pastoral production system, which is practiced in the arid and semiarid peripheral parts of the country, and accounts for about 15-20% of the cattle population and 60% of land area (MoARD, 2007). In this system, livestock farming is the main livelihood and cattle are used to produce milk for the family and excess animals for the market. The third type of production system is the market oriented system, which is a small (representing about 1% of cattle population) but growing component of the sector in urban and peri-urban parts of the country. This system primarily consists of dairies with improved breeds and to some extent feedlot operations (MoARD, 2007).

4.2.3.2 Sampling

A sample size of 300 farmers, about 100 farmers from each production system, was chosen for data collection. This sample size was based on a pragmatic consideration of logistic feasibility and reasonable power of test for the intended statistical analyses. The farmers were sampled from four districts (Gondar Zuria, Habru, Gubalafto, Kobo) in the CLM system, from three districts (Dugda Dawa, Yabello and Dire) in the pastoral system and from two cities (Gondar and Addis Ababa) in the market oriented system. Selection of districts and cities was based on the authors' subjective judgment of representativeness of the production systems and on convenience of accessibility. The difference in the number of districts sampled from the different production systems was a reflection of the proportion of districts in the different production systems.

Because of the absence of any official registration of individual farms and the difference in infrastructure, different approaches were followed in selecting farmers in the different production systems. Sampling of farmers in the CLM and pastoral system was done haphazardly at market places, veterinary clinics and community meetings in the selected districts. In the market oriented system, half of the sub-cities (5 sub-cities) from each city was chosen randomly. The selection of farmers in this system was done in a systematic way by travelling in the streets of the selected sub-cities. Selection of farms started at one end of a randomly selected street and continued by skipping the immediate neighboring farm. This selection procedure was repeated in other streets until the required sample size (10 farmers) for each sub-city was reached.

The questionnaire was prepared in English and translated into Amharic (the local language) for administration (Appendix 4.2). It was administered to the selected farmers by face to face interviews. The study proposal was ethically reviewed and approved by the Institutional Review Board of the University Gondar. Oral informed consent was obtained from each participating farmer after reading a written consent form. The use of oral consent was approved by the Institutional Review Board considering the fact that most of the study participants could not read and write to give their consent in writing. The interviewers confirmed the participants' oral consent by signing on the respective consent form for each interview as per the Board's guideline. The consent form mainly explains about the purpose of the study, the risks and benefits of participation in the study, conditions of confidentiality, the right to refusal or withdrawal from the study, and has a signature space for confirming the participants informed consent. To avoid response bias, farmers were also told that their responses would not be directly used for action by the government and their responses would be handled anonymously throughout the analysis.

4.2.4 Data analysis

The assessments of the intention of farmers to implement FMD control measures and their perceptions about FMD risk and its control in the different production systems were described using frequencies and percentages.

Analyses of the influence of the perceptions on the intentions to implement the proposed FMD control measures were performed for the two control measures that are considered to be most relevant to the Ethiopian situation: 1) vaccination against FMD two times a year using a trivalent vaccine at the cost of the farmer which is estimated at 40 birr/animal/year (simply referred as vaccination with charge hereafter) and 2) herd isolation and animal movement restriction during an outbreak (simply referred as herd_iso & mov_res hereafter).

The influence of perceptions on the intentions to implement the two control measures was analyzed separately using multivariable binary logistic regressions. In the analyses, the intentions to implement the control measures (vaccination with charge and herd_ iso & mov_res) were used as dependent variables, and variables that were set to measure the four constructs of HBM as predictor variables. In a formal HBM analysis, the constructs are used as predictor variables in the form of latent variables themselves measured by several items. However, in this study the individual items (or observed variables) (Table 4.1) were directly used as predictors because of the low internal consistency of the items within the constructs (Cronbach alpha of less than 0.7) (Field, 2005). For the intention to implement vaccination with charge, three variables of perceived susceptibility, two variables of perceived severity, one variable of perceived benefit and three variables of perceived barriers were used as predictors. For the intention to implement herd_iso & mov_res, the same set of variables of perceived susceptibility and perceived severity, one variable of perceived benefit, and one variable of perceived barrier were used.

The effect modifying factors (Table 4.1) on perceptions about the disease and the studied control measure was analyzed using multivariable ordinal logistic regression due to ordinal scale of the perception variables. In these analyses, perception variables that were found significantly associated with intentions in the multivariable binary logistic regressions were subsequently used as dependent variable and the modifying factors (socio –demographic and husbandry variables) as predictors.

The predictor variables that were measured in three points scale of low, medium and high were treated as categorical variables. Before the regression analyses, presence of collinearity among predictor variables was checked using Spearman correlation coefficient. Correlation coefficients greater than 0.9 were considered to indicate the presence of collinearity (Dohoo et al., 2003).The predictor variables were included to the model using the enter method i.e. all the predictor variables are entered at once The fits of the models were assessed using Losmer and Lemeshow test for the binary logistic models and Pearson χ^2 test for the ordinal logistic models. The Pseudo R square measures (Cox and Snell R square, and Negelkerke R square) were used to assess the predictive power in all models (Dohoo et al., 2003). All statistical analyses were performed using the statistical package SPSS (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp).

Table 4.1. The perception and modifying factor variables used in the logistic regression analyses and their relation to the HBM constructs

Variables	Relation to the HBM constructs
Gender	Modifying factors
Age	"
Educational status	"
Production system	"
Cattle herd size	"
Contribution of livestock to livelihood	"
Frequency of FMD occurrence in own herd	Perceived susceptibility
Frequency of FMD occurrence in kebele	"
Trend of FMD outbreak occurrence	"
Impact of FMD relative to other production problems	Perceived severity
Impact of FMD relative to other livestock diseases	"
Effectiveness of vaccination against livestock diseases/FMD	Perceived benefits
Effectiveness of herd_iso & mov_res	"
Cost of FMD vaccination	Perceived barriers
Difficulty of handling animals for vaccination	"
Problem of side effects of vaccination	"
Difficulty of herd_iso & mov_res	"

4.3 Results

The response rate of farmers selected to participate in the study was high; only few of them (<5%) were unable to complete the questionnaire mainly due to time limitations. A total of 293 farmers, 84 from CLM system, 100 from the pastoral system and 109 from the market oriented system completed the questionnaire.

4.3.1 Socio-demographic and husbandry characteristics of the study population

An overview of socio-demographic and husbandry characteristics of the respondent farmers is provided in Appendix 4.1. The majority (85%) of the respondents were male. Relatively, there were more female respondents in the market oriented system than in the other systems. The age of respondents was roughly normally distributed. For most (98%) farmers in the pastoral system livestock keeping was the main livelihood, whereas in the other systems the contribution of livestock to their livelihood was partial or minor. Cattle were the most important species of livestock for all farmers in all systems with the exception of two farmers in the pastoral system, where other species (camel and small ruminants) took prominence.

4.3.2 Farmers' intentions to implement FMD control, and their perceptions about the disease and its control measures

4.3.2.1 Intentions to implement FMD control measures

Farmers' intentions for the proposed control measures are documented in Table 4.2. If an official vaccination program would be launched against FMD, the majority of pastoral (94%) and market oriented (92 %) farmers had a positive intention to vaccinate their cattle at their own costs. However, this intention was much lower (42%) among the farmers in the CLM system. If the vaccination would be given for free, almost all farmers (99%) had the intention to vaccinate their animals. If herds would have to be continuously isolated and animal movement restricted, only 2% of pastoral and 18% of CLM farmers had the intention to comply with this measure. If this measure would be taken only during an outbreak of FMD, 50% of the CLM farmers and 11% of the pastoral farmers had the intention to comply with the measure. The majority of market oriented farmers (>80%) indicated a positive intention to comply with herd isolation and animal movement restriction measures, both in a continuous way and during an outbreak.

Table 4.2. Farmers' intensions to implement FMD control measures in the different production systems

FMD control measures	Response	CLM		Pastoral		Market oriented	
		N[a]	%	N	%	N	%
Vaccination with charge	yes	30	42	94	94	70	92
	no	42	58	6	6	6	8
Vaccination free of charge	yes	70	97	100	100	76	100
	no	2	3	0	0	0	0
Herd isolation and animal movement restriction continuously	yes	13	18	2	2	63	83
	no	59	82	98	98	13	17
Herd isolation and animal movement restriction during an outbreak	yes	36	50	11	11	65	86
	no	36	50	89	89	11	14

[a]N = number of farmers

4.3.2.2 Perceived susceptibility to and severity of FMD

Farmers' perceived susceptibility to and severity of FMD within the various production systems are documented in Table 4.3. All pastoralists, 86% of the CLM farmers and 74% of the market oriented farmers did know the disease FMD, and 97%, 93% and 63 % of the farmers who knew the disease in the respective systems, experienced the disease in their own herd. Most farmers (78%) in the pastoral system reported an annual

Table 4.3. Farmers' perceived susceptibility to and severity of FMD in the different production systems

Variables	Response levels	CLM		Pastoral		Market oriented	
		N	%	N	%	N	%
Perceived susceptibility							
Frequency in own herd, one occurrence in	1 year	3	5	76	78	7	15
	2 years	12	20	16	17	26	55
	5 years	40	67	5	5	7	15
	10 years	5	8	0	0	7	15
Frequency in kebele, one occurrence in	1 year	6	10	90	90	14	19
	2 years	11	17	10	10	44	59
	5 years	42	67	0	0	11	14
	10 years	4	6	0	0	6	8
Trend of occurrence	increasing	4	6	91	91	10	13
	unchanging	43	66	9	9	50	66
	decreasing	18	28	0	0	16	21
Perceived severity							
Impact relative to other production problems	low	62	86	12	12	33	43
	medium	9	13	45	45	34	45
	high	1	1	43	43	9	12
Impact relative to other disease problems	low	30	42	13	13	8	10
	medium	30	42	43	44	50	66
	high	12	16	42	43	18	24

occurrence of FMD in their herds. Nonetheless, the majority of the CLM farmers (67%) and market oriented farmers (55%) reported a frequency of every five and two years, respectively. The frequency of occurrence of FMD at the level of their kebeles followed a similar trend. The majority (91%) of farmers in the pastoral system perceived that the frequency of FMD occurrence had increased through time. However, the majority of farmers in the CLM (66%) and market oriented (66%) systems perceived that the frequency of occurrence had not changed through time.

The impact of FMD relative to production problems in livestock farming was perceived as low by majority of CLM farmers (86%) and as medium by the majority of the pastoralists (45%) and market oriented farmers (45%). When the FMD impact was compared with the consequences of other livestock diseases, it was perceived as medium by the majority of farmers. However, the overall tendency in the CLM was towards a low perceived impact while in the pastoral and market oriented systems it was towards a high perceived impact.

4.3.2.3 Perceived benefits and barriers of FMD control measures

The farmers' perceived benefits and barriers of potential FMD control measures such as vaccination, and herd_iso & mov_res are documented in Table 4.4. Most farmers in all production systems perceived vaccination as a highly effective disease control measure. The majority of farmers in all three systems considered herd_iso & mov_res also as highly effective in controlling FMD but absolute proportions were smaller than those of vaccination (Table 4.4).

The majority of farmers; 82% in the CLM system, 44% in the pastoral system, and 38% in market oriented system perceived the costs of vaccination as high. Nonetheless, still a significant proportion of pastoral farmers (26%) and market oriented farmers (33%) considered the costs of FMD vaccination as medium. The difficulty of trekking animals to vaccination centers (when needed) and handling animals for vaccination was perceived as low by the majority (96%) of CLM farmers and market oriented farmers (38%), but high by the majority of pastoral farmers (35%). Most farmers perceived problem of side effects vaccination as low. Difficulty of herd_iso & mov_res was perceived as high by the majority of farmers in pastoral system (73%) and CLM system (65%). Most market oriented farmers considered the difficulty of applying herd_iso & mov_res as medium or low.

Table 4.4. The farmers' perceived benefits and perceived barriers of implementation of potential FMD control measures in the different production systems

Variables	Response	CLM		Pastoral		Market oriented	
		N	%	N	%	N	%
Perceived benefits							
Effectiveness of vaccination	low	0	0	1	1	0	0
	medium	2	3	1	1	21	28
	high	70	97	98	98	55	72
Effectiveness of herd_iso & mov_res	low	9	12	3	3	1	1
	medium	10	14	24	24	18	24
	high	53	74	73	73	57	75
Perceived barriers							
Cost of vaccination	low	10	14	30	30	22	29
	medium	3	4	26	26	25	33
	high	59	82	44	44	29	38
Difficulty of trekking and handling animals for vaccination	low	69	96	33	33	29	38
	medium	3	4	32	32	21	28
	high	0	0	35	35	26	34
Problem of side effects of vaccination	low	69	96	100	100	52	69
	medium	2	3	0	0	23	30
	high	1	1	0	0	1	1
Difficulty of herd_iso & mov_res	low	19	27	8	8	26	34
	medium	6	8	19	19	37	49
	high	47	65	73	73	13	17

4.3.3 Perceptions affecting the intentions to implement FMD control measures

Farmers' perceived cost of vaccination (perceived barrier) was identified as the most important perception that was significantly associated with the intention to implement vaccination with charge (Table 4.5). The odds of the intention to implement vaccination with charge was significantly lower in respondents who perceived the cost of vaccination as high (OR (95%CI) = 0.04 (0.004-0.32), P = 0.004) than of those who perceived the cost of vaccination as low.

Table 4.5. Perception variables significantly associated with farmers' intention to apply vaccination with charge

Perception variable	Levels	Coefficients	Standard Error	Odds Ratio (95% CI)	P- value
Vaccination cost					0.002
	high	-3.30	1.10	0.04 (0.004-0.32)	0.004
	medium	-0.37	1.54	0.69 (0.034 -14.26)	0.739
	low	1*	1	1	

* The value 1 in the row represents the reference category of the categorical variable.
Number of data points = 233; Model fit: Hosmer and Lemeshow test χ^2 = 4.88, df = 8, P = 0.777; Psuedo R square: Cox-Snell R square = 0.351; Nagelkerke R square = 0.358).

Perceived difficulty (perceived barrier) was again found to be the most important perception that was significantly associated with the implementation of herd_iso & mov_res measure (Table 4.6). The odds of intention to implement herd_iso & mov_res was significantly lower for farmers with high perceived difficulty (OR (95%CI) = 0.05 (0.02-0.14), P < 0.001) than for those with a low perceived difficulty of implementing the measure. Perceived frequency of outbreaks in the kebele herds (perceived susceptibility) and perceived effectiveness of herd_iso & mov_res measure (perceived benefit) were also significantly associated with intention to apply herd_iso & mov_res measure (Table 4.6). The odds of intention to implement herd_iso & mov_res was significantly higher for farmers with medium perceived susceptibility (OR (95% CI) = 3.92 (1.20- 12.70), P = 0.023) than farmers with low perceived susceptibility to FMD. Similarly the odds of intention to implement this measure was significantly higher for farmers with high perceived effectiveness (OR (95% CI) = 3.36(1.12-10.02), P = 0.030) and medium perceived effectiveness (OR (95% CI) = 3.47(1.11-10.87), P = 0.033) than farmers with low perceived effectiveness of herd_iso & mov_res measure.

Table 4.6. Perception variables significantly associated with farmers' intention to apply herd_iso & mov_res control measures

Perception variable	Levels	Coefficients	Standard Error	Odds Ratio (95% CI)	P- value
Vaccination cost					0.002
	high	-3.30	1.10	0.04 (0.004-0.32)	0.004
	medium	-0.37	1.54	0.69 (0.034 -14.26)	0.739
	low	1*	1	1	

* The value 1 in the rows represents the reference category of the categorical variables.
Number of data points = 233; Model fit: Hosmer and Lemeshow test χ^2 = 2.96, df = 8, P = 0.937; Psuedo R square: Cox-Snell R squar e = 0.482; Nagelkerke R square = 0.645)

4.3.4 Modifying factors that influence perceptions that are significantly associated with intentions to implement FMD control measures

Production system and age of the farmers were the modifying factors that significantly affected the perception of cost of vaccination which was the only significant perception that influenced intention to implement vaccination with charge measure (Table 4.7). There was a significantly lower odds for farmers in the market oriented system (OR (95%CI) = 0.13 (0.05-0.35), P<0.001) and pastoral system (OR (95%CI) = 0.10 (0.03 -0.34), P<0.001) to perceive the costs of FMD vaccination as high than for farmers in the CLM system. An increase in the age of the farmers was observed to significantly increase the odds of perceiving the cost of FMD vaccination as high (OR (95% CI) = 1.03(1.01-1.05), P = 0.015) i.e. an increase in the age of farmers by one year increases the odds of perceiving the cost of vaccination as high by 3%.

Production system was the only modifying factor that significantly affected the perceptions that were significantly associated with intention to apply herd_iso & mov_res measure (perceptions of susceptibility, benefits and barriers) (Table 4.7). The odds of perceiving higher susceptibility (in terms of frequency of outbreak occurrence in kebele) was significantly higher in the market oriented system (OR (95%CI) = 6.06 (2.09 - 17.60), P = 0.001) and in the pastoral system (OR (95%CI) = 244.21 (48.48 – 1230.34), P < 0.001) than in the CLM system. The odds of perceiving higher benefit (perceived effectiveness of herd_iso & mov_res measure) was significantly lower in the pastoral system (OR (95%CI) = 0.07 (0.02 – 0.25), P <0.001) than in the CLM system. The odds of perceiving higher barrier (perceived difficulty of herd_iso & mov_res measure) was significantly lower in the market oriented system (OR (95%CI) = 0.17 (0.07 -0.45), P < 0.001) than in the CLM system.

Table 4.7. Modifying factors that affect perceptions significantly associated with intentions to implement FMD control measures*

Factors	levels	Coefficients	Standard Error	Odds Ratio (95% CI)	P- value
Cost of FMD vaccination[a]					
Production system					<0.001
	Market oriented	-2.03	0.50	0.13 (0.05-0.35)	<0.001
	Pastoral	-2.34	0.65	0.10 (0.03 -0.34)	<0.001
	CLM	1**	1	1	
Age (in years)		0.03	0.01	1.03(1.00-1.05)	0.015
Frequency of outbreak occurrence in kebele[b]					
Production system					<0.001
	Market oriented	1.80	0.54	6.06 (2.09- 17.60)	0.001
	Pastoral	5.50	0.83	244.21 (48.48 – 1230.34)	<0.001
	CLM	1	1	1	
Herd_iso & mov_res effectiveness[c]					
Production system					<0.001
	Market oriented	0.26	0.56	1.30 (0.44 – 3.85)	0.641
	Pastoral	-2.70	0.67	0.07 (0.02 – 0.25)	< 0.001
	CLM	1	1	1	
Herd_iso & mov_res difficulty[d]					
Production system					<0.001
	Market oriented	-1.75	0.47	0.17 (0.07 -0.45)	<0.001
	Pastoral	0.57	0.61	1.77 (0.54 – 5.79)	0.349
	CLM	1	1	1	

*The table contains four models for the four significant perception variables as presented in Tables 4.5 and 4.6. Reference marks a, b, c and d provide additional information for each of the four models.

**The value 1 in the rows represents the reference category of the categorical variables.

[a] Number of data points (N) = 237; Model fit: Pearson χ^2 = 361.1 df=360, P = 0.474; Psuedo R square: Cox-Snell R square = 0.172; Nagelkerke R square = 0.198).

[b] N = 227; Model fit: Pearson χ^2 = 341.6, df=346,P = 0.557; Psuedo R square: Cox-Snell R square = 0.537; Nagelkerke R square = 0.611).

[c] N = 237; Model fit: Pearson χ^2 = 400.5, df=360,P = 0.069; Psuedo R square: Cox-Snell R square = 0.529; Nagelkerke R square = 0.603).

[d] N = 237; Model fit: Pearson χ^2 = 355.5, df=360,P = 0.557; Psuedo R square: Cox-Snell R square = 0.212; Nagelkerke R square = 0.244).

4.4 Discussion

4.4.1 Intentions to implement FMD control measures

In this study, farmers' intentions to implement different proposed FMD control measures were explored. Almost all farmers had the intention to vaccinate their cattle against FMD if vaccination would be given free of charge. If the vaccination would be given with charge, the intention to vaccinate decreased to some extent in the pastoral and market oriented system and significantly in the CLM system. This indicates that if full participation of farmers is to be achieved in a vaccination campaign against FMD, the problem with the vaccination cost has to be addressed, particularly for the CLM system where vaccination cost appeared very constraining. This could be done through subsidies or rigorous extension to convince CLM farmers about the cost effectiveness of vaccination. However, the benefit of vaccination at herd level for the CLM could be marginal or nonexistent as inferred from cost per outbreak estimations and disease outbreak incidence studies by Jemberu et al. (Jemberu et al., 2015, 2014)

Farmers' intention to implement herd_iso & mov_res both as a continuous measure and as measure only during outbreaks varies among the production systems. The intention was low for subsistence systems (CLM and pastoral) but high for market oriented system. Given the current husbandry practice in the subsistence systems, which is dependent on common grazing and watering areas, a continuous implementation of herd_iso & mov_res would be unrealistic especially in the pastoral system. However, implementing this measure at least during outbreaks is of vital importance to control highly contagious disease like FMD and needs strong extension work.

4.4.2 Perceptions significantly influencing the intentions to implement FMD control measures

In the performed analyses, the most important factor identified to significantly affect the intention to implement vaccination against FMD with charge was the perceived barrier (cost of vaccination). This is consistent with literature which indicates that among the four HBM variables (constructs), the perceived barrier has been the most powerful in predicting behavior across various study designs and behaviors (Carpenter, 2010; Champion and Skinner, 2008; Janz and Becker, 1984; Tanner-Smith and Brown, 2010). Previous observations in animal disease control programs also showed that uptake of livestock vaccination is cost sensitive, especially in farmers of developing countries (Paton and Taylor, 2011). Subsidizing the cost of FMD vaccine may be needed to ensure wide participation of farmers in vaccination programs to achieve sufficient herd immunity for controlling the disease. The conventional FMD vaccine in use is one of the most expensive livestock vaccines (FAO and OIE, 2012) , and reducing its cost should be an area of future research to increase the success in global control of the disease.

Like in vaccination, the intention to implement herd_iso & mov_res was significantly influenced by perceived barrier (difficulty of herd_iso & mov_res) indicating the importance of perceived barrier in predicting health related behavior. The difficulty of herd isolation and movement restriction is inherent to the husbandry system of traditional extensive livestock production. This problem could only be improved by modernizing the husbandry system and by gradually ending communal grazing practice. Perception of susceptibility (high frequency of FMD outbreak occurrence) was also found associated with positive intention to implement herd_iso & mov_res measure and this was in agreement with common findings that perception of susceptibility is an important predictor of preventive health behavior (Janz and Becker, 1984). Providing information about the risk of the disease to the farmers will encourage the desired behavior with regard to FMD control.

The perceived barrier (cost of vaccination) for vaccination with charge control measure was in turn significantly influenced by the type of production system and age of the farmers. Vaccination cost was perceived high by CLM farmers (high perceived barrier) as compared to the farmers in the other systems which could be due to the relatively lesser importance of livestock in their livelihood. Any FMD control program using vaccination in Ethiopia needs to address the vaccine cost problem in this system which is the dominant production system in the country. Increase in age was associated with increased perception of high cost of vaccination. Literature on agricultural technology adoption mostly indicated younger farmers to be more open to adopt farming technologies than older farmers (Adesina and Baidu-Forson, 1995; Howley et al., 2012).

The production system was also the most important factor that modified the perceptions about the herd_iso & mov_res measure. Perception of difficulty of herd_iso & mov_res was higher for subsistence systems compared to the market oriented system. This is obviously related to the farming system in which they mostly use communal grazing area and watering points, and in case of pastoral systems, have to move from place to place in search of pasture. Given the specific characteristics of the subsistence systems the use of movement control as disease control measure will continue to be a challenge in Ethiopia.

4.5 Conclusions

In this study farmers' intentions to implement potential FMD control measures and their perceptions about the disease and its control measure are explored, the perceptions that have significant influence on the control intentions are identified, and the socio-demographic and husbandry factors that modify these perceptions are recognized. Farmers' intentions to implement the proposed FMD control measures except for free vaccination are generally low with some variation among the production systems. The perceptions of barriers such as cost of vaccination and difficulty of herd isolation and movement restriction were found as the most important perceptions that significantly influenced the intentions to implement FMD control measures. These perceived barriers should be targeted to increase farmers' participation in official disease control programs. The type of production system was seen as the main factor that influenced the relevant perceptions and hence indirectly the intentions to implement the control measures. Promotion programs aiming at increasing farmers 'motivation to participate in FMD control should, therefore, benefit from the insights in the differences in perceptions among the production systems.

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Appendixes

Appendix 4.1. Socio-demographic and husbandry characteristics of sampled farmers in the different production systems

Variables	Levels	CLM		Pastoral		Market oriented	
		N[a]	%	N	%	N	%
Age (years)	20-30	7	8	43	43	4	4
	31-40	19	23	23	23	34	31
	41-50	25	30	15	15	38	35
	50-60	11	13	11	11	13	12
	>60	22	26	8	8.0	19	17
Gender	F	1	1	13	13	28	26
	M	83	99	87	87	81	74
Education	none	36	43	78	78	8	7
	primary	44	53	19	19	48	45
	secondary	3	4	3	3	43	40
	tertiary	0	0	0	0	8	8
Cattle herd size	1-10	72	92	12	12	79	75
	11-20	4	5	35	35	26	25
	21-30	0	0	21	21	0	0
	30-40	2	3	8	8	0	0
	>40	0	0	14	14	0	0
Livestock as source of livelihood	main	10	12	98	98	30	27
	partial	7	8	2	2	51	47
	minor	67	80	0	0	28	26
Cattle as main species	yes	84	100	98	98	109	100
	no	0	0	2	2.0	0	0

Chapter 4

Appendix 4.2. Questionnaire on farmers' perceptions and intentions to implement foot and mouth disease control measures.

I. Farm profile

1. Production system: Crop-livestock mixed / Pastoral / Market oriented
2. Name of the respondent (optional) ______________________
3. Sex: male / female
4. Age (years) ______________________
5. Educational status (illiterate - higher education) ______________________
6. Experience in livestock keeping (years) ______________________
7. Livestock owned (species and number) ______________________
8. Number of cattle owned by age group and purpose:
   Cow ___________ ______________________
   Ox/bull ___________ ______________________
   Young bull/ heifers ___________ ______________________
   Calves ___________ ______________________
9. Contribution of livestock to livelihoods
   Major / Partial / Minor
10. The livestock species that has a main contribution to the livelihoods (give order)
    Cattle / Small ruminants / Camel / Equines / Poultry

II. Foot and mouth disease risks / susceptibility

11. Have your ever heard of a livestock disease called FMD?
    Yes No
12. If yes, can you describe it (symptoms and epidemiological features)?

Continue with questionnaire if farmer knows FMD by describing one or more of the following features

a. Lameness (foot lesion) and salivation (mouth lesion) in cattle and/ or small ruminants
b. Foot lesion in cattle and/ or small ruminants that is contagious
c. Mouth lesion in cattle and/ or small ruminants that is contagious
d. Lameness or mouth lesion, and blisters (sores)on teats of cows

13. Have you ever had an FMD outbreak in your cattle herd ?
    Yes / No
14. If so, when was the last outbreak you experienced?
    this year / last year / 2 years ago / 3 years ago / before 5 years
15. How frequently did an FMD outbreak occur in your herd during the last ten years?
    every year / every two year / every five year / every ten year

16. Have you ever had an FMD outbreak in your kebele?
    Yes / No
17. When was the last outbreak you experienced in the kebele?
    this year / last year / 2 years ago / 3 years ago / before 5 years
18. How frequently did an FMD outbreak occur in your kebele during the last ten years?
    every year / every two year / every five year / every ten year
19. The trend in the occurrence of FMD is in the last five years
    decreasing / unchanging / increasing

III. Impacts of FMD

20. The problem of foot and mouth disease in cattle production as compared to all other (disease and non-_disease) production problems is considered
    low / medium / high
21. The problem of foot and mouth disease in cattle production as compared to all other disease problems in cattle is
    low / medium / high

IV. Effectiveness of FMD control measures

22. Effectiveness of vaccination to prevent FMD (or any other livestock disease)?
    low / medium / high
23. Effectiveness of restricting movement and avoiding mixing of your herd with other herd in preventing an introduction of FMD?
    low / medium / high

V. Possible barriers to implement FMD control

24. Difficulty to vaccinate against FMD at a cost of 40 birr/year/per animals
    low / medium / high
25. Difficulty to trek and handle every animal of your herd two times a year for vaccination
    low / medium / high
26. Side effects of vaccination against FMD (any cattle disease)
    low / medium / high
27. Difficulty to restrict movement and to avoid mixing of animals during a FMD outbreak (for a period of 3 months)
    low / medium / high

VI. FMD prevention/control intentions

28. Would you vaccinate your cattle 2 times/year if the government provides the vaccine at market price (i.e. 40 birr/animal /year) ?
    Yes / No
29. Would you vaccinate your cattle 2 times /year if the government provides the vaccine for free?
    Yes / No
30. If it is necessary to keep your cattle isolated from other herds all the time (continuously) and to control their movements to protect your cattle from an FMD, would you do it?
    Yes / No
31. If it is necessary to keep your cattle isolated from other herds during an outbreak of FMD and to control their movements (up to three months) to protect your cattle from FMD, would you do it?
    Yes / No

Chapter 5

Mathematical Modelling of the Transmission Dynamics of Foot and Mouth Disease Outbreaks in the Subsistence Livestock Production Systems of Ethiopia

Wudu T. Jemberu, Don Klinkenberg, Monique Mourits, Henk Hogeveen

Abstract

Mathematical epidemiological models have become widely used in evaluating, prioritising and deciding among alternative disease management activities. Such models that provide relevant information are not available to study the endemic FMD situation in Ethiopia. The objective of this study was, therefore, to explore the possibility of developing and parameterizing a simple FMD transmission mathematical model for a typical district in the subsistence livestock production systems of Ethiopia. The model was particularly aimed at predicting morbidity, mortality, and duration of FMD outbreaks. These outputs of the model could then be used for further economic analysis of FMD and its control. A stochastic SIR (susceptible-infectious-recovered) model was formulated and parameterised with data form various sources (e.g. literature and field data). Key model parameters such as the basic reproductive ratio (which was used to derive transmission parameter) and rate of loss of immunity were estimated from field cross-sectional sero-prevalence data by maximum likelihood estimation. Simulation of the SIR model, using the estimated parameters, resulted in prediction of outbreak characteristics that were not reliable enough when compared with the actual field outbreak data. Several unavoidable simplifying assumptions due to the poor quality of available data contributed to the limitations of the model performance. These assumptions are discussed, and areas for future improvement of the model are highlighted.

Key words: foot and mouth disease, Ethiopia, mathematical model, SIR, transmission dynamics

5.1 Introduction

Foot and mouth disease (FMD) is a highly transmissible transboundary animal disease that affects all cloven hoofed animals. FMD is endemic in Ethiopia with reports of several outbreaks every year (Jemberu et al., 2015). It is economically the most important disease of livestock because of its severe impact on production and trade of animal and animal products. There has never been any official control plan against the disease in Ethiopia except for vaccinations in some commercial dairy farms in urban and peri-urban areas that keep cross-bred animals. There is, however, an increasing interest to launch a control program against FMD to minimize the disease's impact on production and to boost export trade in animal and animal products (Thomson, 2014). Designing efficient disease control programs requires an understanding of the epidemiological dynamics of the disease and its control within the prevailing production systems.

Mathematical modelling can help to understand the dynamics of infectious agents in host populations (de Jong, 1995). Mathematical epidemiological models have become widely used tools in evaluating, prioritising and deciding among alternative disease management activities (Willeberg et al., 2011). They are used to study 'what if' scenarios and to provide decision-makers with information about the consequences of a disease outbreak and expected impacts of the control strategies.

Mathematical models for foot and mouth disease (FMD) transmission have been extensively used to inform policy-making on the disease control, both for contingency planning (Bates et al., 2003; Berentsen et al., 1992) before an epidemic, and for real time evaluation of the control strategies applied during an epidemic (Keeling et al., 2001; Morris et al., 2001). Most FMD models in the literature are based on an (hypothetical) incursion of the disease in disease free developed countries for the purpose of evaluation of the disease impact and are basically spatially explicit farm based transmission models (Bates et al., 2003; Durand and Mahul, 2000; Keeling et al., 2001; Martínez-López et al., 2010). This is due to the fact that these countries direct their control measures at farm level (like stamping out). Infections in individual animals are not of direct relevance in such situations.

Mathematical transmission models, to be used as tool in informing epidemiologically and economically effective disease management policy, should be developed and parameterised for the specific production system and animal population structure under consideration. The situation in endemic areas under traditional production systems such as in Ethiopia, however, differs from the epidemic situations as reflected in the models described above. In the subsistence extensive production systems there is mixing of animals from different herds. Stamping out is also not an economically feasible and epidemiologically essential control tool in these systems and hence modelling at individual animal level based on the assumption of uniform mixing (non-spatial) is the relevant approach in understanding the disease dynamics and control impacts. Such uniform mixing mathematical modelling approaches have been used by various authors in understanding the transmission dynamics of transboundary disease in endemic situations in traditional livestock systems as, for example, for FMD (Perry et al., 1999) , for rinderpest (Mariner et al., 2005) and for contagious bovine pleuropneumonia (Lesnoff et al., 2004; Mariner et al., 2006, 2005).

Such transmission model for FMD is currently non-existent in Ethiopia. The objective of this study was, therefore, to explore the possibility of developing and parameterizing a simple FMD transmission mathematical model for a typical district that is representative of crop livestock mixed (CLM) and pastoral livestock farming systems of Ethiopia. The model was particularly aimed at predicting the magnitude (morbidity and mortality), and durations of FMD outbreaks with and without control measures in place, and to use these outputs of the model for further economic analysis of FMD and its control.

5.2 Materials and methods

5.2.1 Model structure

Compartmental or state transition models serve as a base mathematical framework for understanding the complex dynamics of disease transmission within a population (Anderson and May, 1979) by stratifying the population into compartments, reflecting the health status with respect to the pathogen in the system. In this study, a classic state transition model has been used to represent the dynamics of FMD in the endemic situation of Ethiopia based on the three principal health states: Susceptible, Infected (infectious) and Recovered (immune), abbreviated as SIR, with population size S(t), I(t), and R(t) respectively, and randomly mixing within districts. The district total cattle population is denoted by N = S(t)+I(t)+R(t), where S, I, R >= 0 and total population N is constant with time. The model was applied only to cattle as the main hosts for FMD in Ethiopia are cattle.

The structure of the SIR model is shown in Figure 5.1. The model reflects an open population model where calves are born (ϕ) into the susceptible state, and a non-specific mortality (μ) occurs in all states. FMD specific mortality (μ_s) occurs only in the infected state. The basic assumption for this model is that the modelled cattle population is in a demographic steady state in such a way that birth and death rates are equal, and deaths are immediately replaced by births so that the total size N of the population remains constant all the time during the simulation.

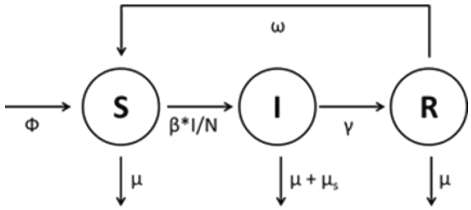

Figure 5. 1. Structure of the SIR model. Arrows indicate transitions of individual cattle form one state to another state with ϕ = birth rate; μ= death rate; β*I/N = rate of transmission; γ = rate of recovery; μ_s = FMD specific mortality rate, and ω = rate of immunity loss.

The deterministic equivalent of the model is mathematically represented by the following set of differential equations (Eqs.1-3):

$$\frac{dS}{dt} = \Phi - \beta\frac{SI}{N} - \mu S + \omega R \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$\frac{dI}{dt} = \beta\frac{SI}{N} - (\gamma + \mu + \mu_s)I \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

$$\frac{dR}{dt} = \gamma I - (\mu + \omega)R \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

The transmission was formulated as mass action (frequency dependent transmission) instead of Pseudo mass action (density dependent) because districts are large areas where an increase in population may not directly increase the contact rate between animals.

5.2.2 Model inputs

Model inputs (parameter values and variables) were obtained in two ways: directly from literature or estimated from available secondary data sources.

Parameter and variable values that are used from literature are presented in Table 5.1. Model variables such as the initial numbers of susceptible and immune animals were based on the average district FMD sero-prevalence in relation to the average district cattle population (Appendix 5.1). Seropositive animals represented initially immunes and seronegative animals represented initially susceptible animals. The average sero-prevalences for the two production systems, CLM and Pastoral, were derived from weighted averages of the district sero-prevalence data sets in the respective systems (see Appendix 5.1).

Table 5.1. Parameters and variables of the SIR model used from literature

Parameters /Variables	Description	Values	Source
Rate of recovery (γ)	Rate of recovery from infectious state (inverse of infectious period)	0.2222 /day	Mardones et al., (2010)
Death rate (μ)	Death rate in the population from any cause other than FMD	0.000247/day	CAS (2013)
FMD specific death rate (μ_s)	FMD Mortality rate from infected state (Case fatality rate)	0.006667/day	Nigussie (2010)
Average district cattle population (N)	The average cattle populations of CLM districts and pastoral districts	119000 heads	CSA (2003)(projected for 2013)
Initially susceptibles (S_0)	Average number of sero-negative animals	83% for CLM, 84% for Pastoral	Compiled from sero-prevalence data set presented in Appendix 5.1
Initially immunes (I_0)	Average number of sero-positive animals (proxy for initially immunes)	17% for CLM, 16% for pastoral	*Idem*

Two parameters of the SIR model, transmission rate parameter (rate of infectious contacts made by a single infectious individual, β) and rate of loss of recovery immunity (ω) were estimated from cross-sectional sero-prevalence data.

District level cross-sectional FMD sero-prevalences were compiled from 82 districts; 41 districts in the CLM and from 41 districts in pastoral production systems. The data were collected from published sero-prevalence surveys and from national annual sero-surveillance results. The published survey estimates were searched from electronic bibliographic databases (Scopus, Web of Science, and Google Scholar) and sero-surveillance results were taken from the disease diagnosis databases of the National Animal Health Diagnosis and Investigation Centre, Ethiopia. In both cases, sero-prevalence data were used from the years 2008 to 2012.

The β was derived from the basic reproductive ratio (R_0), which itself was estimated from the sero-prevalence data described above. R_0 is one of the important quantities in epidemiology which refers to the average number of secondary cases arising from a primary case in an entirely susceptible population (Keeling and Rohani, 2008). An infection can spread in a population only when R_0 is greater than one, i.e., when on average every infected animal is able to infect more than one animal during its infectious period. In terms of SIR model parameters, an infection can spread only when the removal rate of infectious individuals through recovery, death or other means is smaller than the transmission rate. The ratio of the removal rate to the transmission rate is called the relative removal rate, and its inverse gives the R_0 (Keeling and Rohani, 2008).

From Eq.2, the relative removal rate is $(\gamma + \mu + \mu_s)/\beta$; and the inverse, R_0, will be $\beta/(\gamma + \mu + \mu_s)$. From this relation β is derived as

$$\beta = R_0 * (\gamma + \mu + \mu_s) \ldots\ldots (4)$$

The other SIR model parameter estimated from the sero-prevalence data was ω, the rate of immunity loss. A maximum likelihood estimation as described below was used to estimate both R_0 and ω, from the sero-prevalence data.

For estimating R_0 and *ω,* the dynamics of FMD in a district was conceptualized by an introduction of the FMD virus in a district at random moments (by a Poisson process), with an average frequency of outbreaks as estimated by Jemberu et al. (2015); viz. every 50 months in the CLM system and every 31 months in the pastoral system. After each virus introduction, it is assumed that an outbreak develops quickly and the sero-prevalence increases instantly. The amount by which the sero-prevalence increases depends on the sero-prevalence (proportion of immunes) at the time of introduction and on $R_{0.}$ The final size function of an outbreak model gives a relation between the R_0, the proportion of susceptible animals before an outbreak, and the final size (proportion of the population that is infected during the course of an outbreak)), as indicated in Eq. 5:

$$R_\infty = S_0(1 - e^{-R_\infty R_0}) \ldots\ldots\ldots (5)$$

where;
R_∞ = final size
S_0 = Proportion of the population that is susceptible before the outbreak
R_0 = Basic reproductive ratio

Between the outbreaks, the sero-prevalence decreases, by rate *ω,* because of loss of immunity. If this process of sero-prevalence increase during outbreaks and decrease between outbreaks occurs in many districts simultaneously but independently, the cross-sectional sero-prevalence data sets which are described before can be regarded as a random sample of this process in time. The data can thus be used to estimate R_0 and *ω*.

A simulation model representing the sero-prevalence dynamics was programmed as a function of R_0, ω and frequency of virus introduction (λ) in rootSolve package (Soetaert, 2010) of the R software (R Core Team, 2013; version 3.0.2) (Appendix 5.2). The model was simulated for 50,000 districts (replications) for a duration of 200 months. The endpoints of these simulations represent a distribution of sero-prevalences across districts. The distributions of these simulated sero-prevalences were used to calculate the likelihood of the field cross-sectional sero-prevalences data sets. A grid of likelihood values for different combinations of R0 and ω was simulated, and R_0 and ω values that resulted in the maximum log likelihood of the observed cross-sectional sero-prevalence data sets were identified as the best parameters that represent the data. The 95% confidence interval for R_0 and ω values were determined using the profile log likelihood method (Stryhn and Christensen, 2003). This was done by searching over the grid of log likelihood values, and the lowest and highest R_0 and ω that corresponded with likelihood values of 1.92 points less than maximum log likelihood value were taken as the lower and upper limits of the 95% confidence intervals of the parameters.

5.2.3 The SIR Model simulation

The stochastic SIR simulation model was programmed in the R software (R Core Team, 2013; version 3.0.2) (Appendix 5.3). Simulations were run separately for the CLM and pastoral system parameters. To mimic the stochastic nature of the real world, the number of animals that moved between different states in the model in each iteration was sampled randomly from a binomial probability distribution. The model was simulated on a daily basis up to four years and was run for 1,000 iterations. The recorded results of the simulations included the proportion of major outbreaks (a major outbreak was defined as an outbreak that spreads across a substantial proportion of the population, and in this study, outbreaks resulting in > 500 infected animals were considered as major); and morbidity, mortality and duration of the major outbreaks. The proportion of persistent outbreaks in the major outbreaks was also recorded.

5.2.4 Model validation

The validity of the model was evaluated by comparing the model's predicted morbidity and mortality, and duration of an outbreak with field outbreak data collected from the six districts; three from CLM and three from pastoral production systems (Jemberu et al., 2014).

5.3 Results

5.3.1 Description of the sero-prevalence data

The cross-sectional FMD sero-prevalence data that were used for parameter estimation R_0 and ω are provided in Appendix 5.1. The sero-prevalences varied from zero to 60% in the CLM system and from zero to 30% in the pastoral system. In Figure 5.2, the ordered cross-sectional sero-prevalences (y-axes) are plotted equidistantly in a time period representing the outbreak interval in each of the two production systems (x-axes). The roughly exponential distribution of the ordered sero-prevalences from CLM system corresponds well with the assumed exponential decline of sero-prevalence after an outbreak in an outbreak dynamics (Figure 5.2a). The graph of the pastoral system (Figure 5.2b) does not reflect well the assumed exponential decline of sero-prevalence.

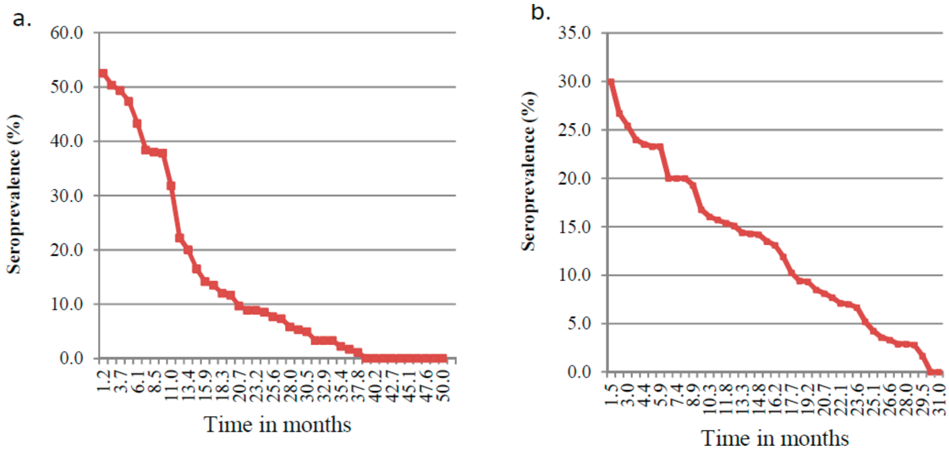

Figure 5.2. The ordered sero-prevalence: (a) in the CLM system with equidistant intervals in an outbreak interval period of 50 months and (b) in the pastoral system with equidistant intervals in an outbreak interval period of 31 months.

5.3.2 Maximum likelihood estimates of R_0 and ω

The maximum log likelihood estimate of R_0 was 1.48 (95%CI:1.40-1.81) for the CLM system and 1.20 (95%; 1.17- 1.25) for the pastoral system. The corresponding rates of loss of immunity were 0.052 (95% 0.042-0.072) per month for the CLM system and 0.024(0.017-0.037) per month for the pastoral system.

5.3.3 SIR Simulation outputs

The SIR model defined by the variables and best parameter estimates as documented in Tables 5.1 and 5.2 was run under the assumption of the introduction of a single infectious animal within the district to simulate the expected development of the disease in the respective production systems.

The simulation reflecting the transmission of FMD in a typical CLM district resulted in lower proportion of major outbreaks (31%) than minor outbreaks (69%). The final size distribution measured by the estimated number of affected animals during an outbreak is given in Figure 5.3. On average, a major outbreak in a CLM district, infected 51% (90% central range (CR): 50% -52%) of the cattle population and killed about 1.5% (90%CR: 1.4%-1.6%) of the population during the entire duration of the outbreak, which was on average 312 (90%CR: 256-399) days. A typical example of such a simulated outbreak is graphically depicted in Figure 5.4. About 12 % of the major outbreaks showed endemic persistence within a district for more than 4 years (Figure 5.5).

In the pastoral system, the proportion of major outbreaks is even less (12%) than in the CLM system (Figure 5.3). A major outbreak in this system resulted, on average, in an infection of 26% (90%CR: 25% -28%) of the cattle population and deaths of 0.75% (90% CR: 0.70%-0.80%) of the district cattle population during the entire duration of the outbreak which was on average 460 (90% CR: 413-497) days. About 70% of the major outbreaks persisted within a district for at least 4 years (Figure 5.5).

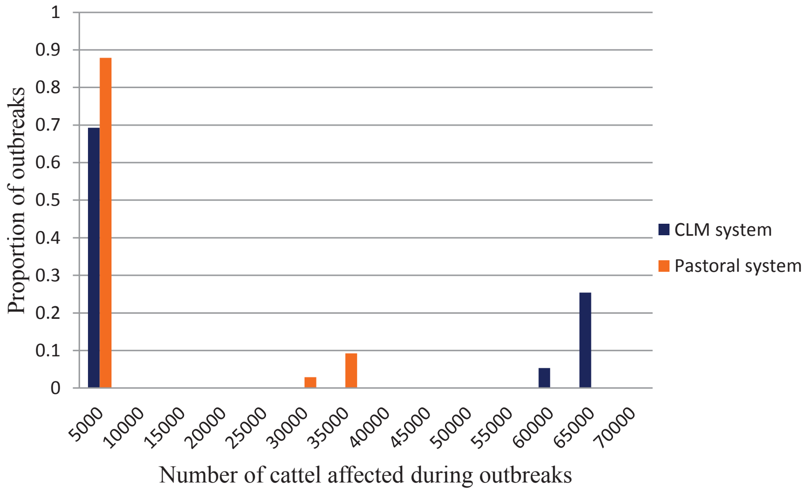

Figure 5.3. Distributions of final sizes of FMD outbreaks for CLM and pastoral production systems.

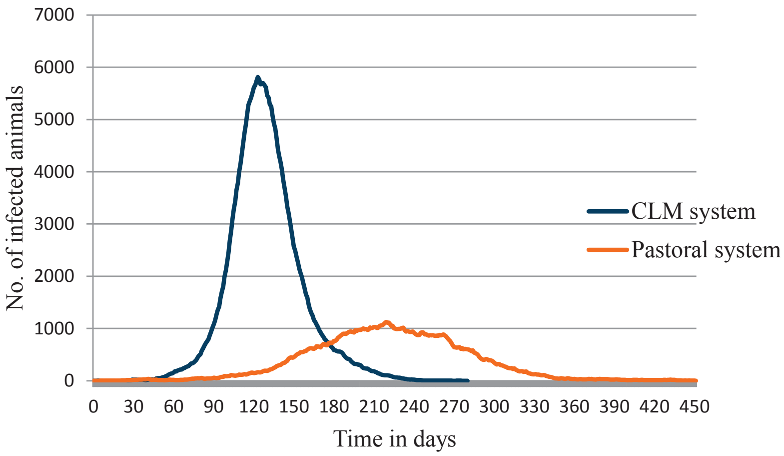

Figure 5.4. Typical examples of epidemic curves of major FMD outbreaks in a district population of CLM and pastoral production systems.

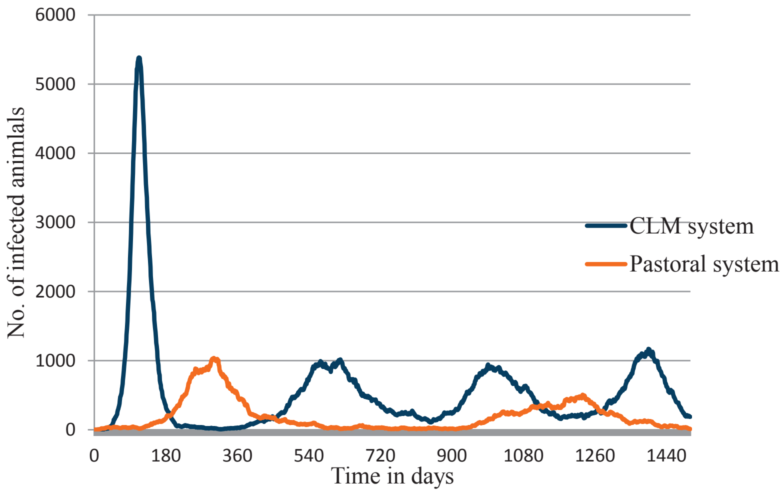

Figure 5.5. Typical examples of epidemic curves showing the endemic persistence of FMD within a district population in CLM and pastoral production systems.

5.3.4 Model validation

The model predicted that about 50% of the cattle population in an average CLM district is affected when a major FMD outbreak occurs, while the outbreak lasts for about 10 months. Field outbreak data on three districts in the CLM production system based on farmers' observations indicated that about 30% of the cattle in a district was affected during an outbreak and the outbreaks lasted for about 3 months (Jemberu et al., 2014). As such, the model predicted a higher morbidity than was actually observed in the field. However, in practice not all infected animals develop clinical sings and will, therefore, not be noted by the farmers, while in the model all infected animals are accounted for. This could partly explain the difference in morbidity rates. In terms of outbreak duration it may be again difficult in the field to exactly determine the end of the outbreak as some animals may continue to be infected without being noticed, while the model is all knowing.

In case of the pastoral system, only 26% morbidity was predicted by the model, while the field outbreak data on three districts of the pastoral system indicated a morbidity of 43% (Jemberu et al., 2014). The simulated average outbreak duration of more than a year was also different from the observed average duration of three months. These differences are difficult to explain.

Although the model predicted relatively better in the CLM system than the pastoral system, generally the prediction are not in correspondence with the field data and, as such, the model cannot be considered reliable in reflecting the real situation.

5.4 Discussion and conclusion

The objective of this study was to explore the possibility of developing and parameterizing a FMD transmission model for a typical district that is representative of the typical CLM and pastoral livestock farming systems of Ethiopia. By definition, a model is only an approximation of reality. As a first attempt to represent the complex process of FMD transmission within the Ethiopian production systems, the developed model appeared not very realistic in the approximation of this process because of several unavoidable simplifying assumptions during parameter estimation resulting from lack of data.

Simplifying assumptions in the maximum likelihood parameter estimation that could have impacted the validity of the model include the following:
1) FMD outbreaks were assumed to be due to only one serotype and the sero-prevalence data obtained from the literature and used for parameter (R0 and ω) estimation were assumed to represent only this serotype. Although it is known that the majority of FMD outbreaks (70%) in Ethiopia are due to serotype O (Jemberu et al., 2015), ignoring the occurrence of other serotypes may be an oversimplification. A consequence of this assumption is that the estimated rate of loss of immunity cannot be accurately estimated, 2) The frequency of outbreaks observed in the field (which actually refers only to major outbreaks) was considered to reflect the frequency of an introduction of infection. However, in reality introduction of infection may or may not cause a major outbreak in a population with less than critical herd immunity. As such the considered frequency of infection introduction was an underestimation of the actual frequency of introduction. This assumption led to a prediction of lower number of major outbreaks than observed in reality, 3) The sero-prevalences of districts used to estimate R0 and ω were assumed to be independent of each other. However, this assumption does not hold true in all cases as the collected data was obtained from districts that were not randomly selected which could have compromised the maximum likelihood estimation, 4) Sero-positive animals were assumed to be immune to infection of FMD. Although it is known that there is high a correlation between in vitro assays of serum antibody and protection in cattle (Doel, 1996), sero-positivity doesn't always guarantee protection which might have led to underestimation of occurrence of major outbreaks. 5) A homogenous mixing of cattle in a district population was assumed. This is a commonly used assumption in epidemic modelling, but it is a very rough assumption in this case as the modelled district unit reflects a large entity, geographically as well as demographically. The first intention was to use a meta population modelling approach with the cattle population at kebele level (subdivisions of district) as modelling unit, and the district population as a meta population. However, absence of outbreak data at kebele level made it impossible to use this meta population modelling approach and the population in the district was taken as a uniformly mixing modelling unit. This assumption might have led to an incorrect estimation of R0 and an incorrect outbreak size distribution/ persistence.

Despite the observed lack of credibility, the attempted model provides a basic framework for developing more realistic outbreak models for FMD and other transboundary livestock disease in Ethiopian endemic situation. The study has revealed important areas of improvement for future modelling. These include collection of serotype specific sero-prevalence data from more districts to improve the estimate of the basic reproductive ratio. Alternatively, R0 and subsequently the transmission model parameter could also be derived from well-structured data collected during active outbreaks from the exponential phase of the outbreak or from age stratified serotype specific sero-prevalence data (Keeling and Rohani, 2008) instead of maximum likelihood estimation employed in this study. Another area improvement is the consideration of a smaller unit for modelling like for example kebele instead of district and applying a meta population modelling approach for a wider geographic region will decrease the effect of the homogenous mixing assumption.

Even with these improvements, the non-spatial model has limitations in simulating the effect of all possible control measures, except for mass vaccination control. To simulate the effect of other control measures like movement restriction, ring vaccination or ring culling, ideally, a spatially explicit model is needed which, however, requires even more data.

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Appendixes

Appendix 5. 1. District sero-prevalence estimates: (a) from formal surveys (b) from regular surveillance.

a. District sero-prevalence estimates from formal surveys compiled from literature

Year of study	District	Sample	Sero-prevalence	Production system*	Source
2008	Amibara	120	4.25	P	(Jenbere et al., 2011)
“	Gewane	134	11.9	P	”
“	Ewa	204	2.9	P	”
“	Chifra	307	5.2	P	”
“	Teletele	248	15.7	P	(Bayissa et al., 2011)
“	Yabelo	296	24	P	”
“	Arero	224	2.9	P	”
“	Awbere	225	14.2	P	(Mohamoud et al., 2011)
“	Babille	159	15.1	P	”
2007/8	Bena Tsemay	60	23.3	P	(Megersa et al., 2009)
“	Dhasanech	30	30	P	”
“	Hamar	60	23.3	P	”
“	South Arri	30	20	P	”
2008/9	Gnangatom	61	13.1	P	(Molla et al., 2010)
“	Jinka	162	4.9	CLM	”
“	Hammer	104	13.5	P	”
	Malle	123	3.3	P	”
“	Semen Aari	142	2.8	P	”
“	Benna tsemay	94	20	P	”
“	Dasenech	84	7.1	P	”
2007/8	Aleta Chucko	45	0	CLM	(Megersa et al., 2009)
“	Aleta wando	60	3.3	CLM	”
“	Awassa Zurya	45	22.2	CLM	”
“	Dalle	60	8.5	CLM	”
“	Darra	45	2.2	CLM	”
“	Hagereselam	30	0	CLM	”
“	Shabadino	60	1.7	CLM	”
“	Wondogenet	45	8.9	CLM	”
“	Arbaminch Z.	90	7.3	CLM	
“	Bonke	60	3.3	CLM	”
“	Chencha	60	3.3	CLM	”
“	Kucha	75	5.3	CLM	”
“	Mirab Abaya	90	1.1	CLM	”

“	Sawla	75	20	CLM	”
“	Surma	120	20	P	(Gelaye et al., 2009)
“	Semen bench	153	5.8	CLM	”
2008	South Achefer	101	52.5	CLM	(Negusssie et al., 2010)
“	Yilmana Densa	98	37.8	CLM	”
“	Bahirdar Zuria	112	38.4	CLM	”
“	Dangela	104	43.3	CLM	”
2012	Habru	218	38.7	CLM	”

*P = pastoral system, CLM = crop-livestock mixed system

b. Sero-prevalences from surveillance data (compiled from registered data from the National animal health diagnostic and investigation center)

Year	District	Sample	Sero-prevalence	Production system
2009	Dilo	153	8.50	P
"	Dolo	179	1.68	P
"	Lare	268	16.04	P
"	Gambella	95	0.00	Cl
"	Abobo	90	6.67	P
"	Itang	322	16.77	P
2010	Shinile	100	7.00	P
”	Tommy	13	0.00	P
”	Jedenay	39	10.26	P
”	Marmarsa	51	23.53	P
	Dile	132	14.39	P
”	Awabar	477	19.29	P
”	Hargel	85	9.41	P
”	Charti	91	7.69	P
”	Elker	78	15.38	P
” ”	Filto	55	25.45	P
	Hargere	120	11.67	CLM
”	Horo	90	8.89	CLM
”	Shabe	76	47.37	CLM
” ”	K.Chale	75	0.00	CLM
”	Oda bultum	75	0.00	CLM
2010	Lay Gaiynt	75	0.00	CLM
”	Metema	75	0.00	CLM
”	Konso	75	49.33	CLM
” ”	Bule	77	0.00	CLM
”	Efrat Gidem	150	0.00	CLM
”	Asayta	71	0.00	P
”	T. Adiaybo	151	50.33	CLM
”	Gimbo	75	12.00	CLM
”	Kersa	28	3.57	P
”	Dawe	7	14.29	P
”	Chitrin	37	8.11	P
”	Ewa	75	9.33	P

2011	KoKosa	129	31.78	CLM
"	Assosa	91	7.69	CLM
"	Bambasi	106	14.15	CLM
2012	Homesha	13	0.00	CLM
"	Tongo	97	16.49	CLM
"	Bego	156	13.46	CLM
"	Gidami	114	9.65	CLM

*P = pastoral system, CLM = crop-livestock mixed system

Appendix 5. 2. The log likelihood model for estimating Ro and ω based on final size function of an epidemic model

```
##'fsfunc' gives the relation between R0 (basic reproductive ratio), z (proportion

##of immunes before an outbreak), and s (proportion of immunes after an outbreak)

fsfunc <- function(R,z,s) {

  exp(-R*(s-z)) - (1-s)/(1-z)

}

##'finalsize' gives the proportion of immunes after an outbreak, given the basic

##reproduction ratio R0, and the proportion of immunes before the outbreak z

finalsize <- function(R0,imm) {

  if(imm > 1-1/R0 - .0001) imm else

  uniroot(fsfunc,c(imm+.0001,1),R=R0,z=imm)$root

}

##'loglikapprox' simulates the outbreak dynamics for a given set of parameters(lambda,
##reprratio, omega). It does so independently for 'nrunits' units,and the simulations
continue ##for 'nrmonths' months. The endpoints of the simulations make up a distribution
of ##seroprevalences across units. After the simulations, this simulated distribution is
used to ##calculate the log-likelihood. Then it plots the simulated distribution together
with the ##dataset for a visual inspection, and it returns the log-likelihood as a
result.dataN ##referes series of samples of individuals and dataX refers series of number
of seropositive ##indivduals in each sample

loglikapprox <- function(lambda,reprratio,omega,dataN,dataX,nrunits,nrmonths) {

  units <- runif(nrunits,0,finalsize(reprratio,0))          #random initial seroprevalence
                                                            in #'nrunits' units

  for(i in 1:nrmonths) {                           #simulations continue for 'nrmonths'
months

    units <- units*exp(-omega*.1)              #each month, first the seroprevalence
decreases

    outbreakunits <- sample(nrunits,rbinom(1,nrunits,lambda*.1))    #each month, outbreaks
                                                                    #occur in randomly
                                                                    #selected units

    if(length(outbreakunits)>0) {

      for(j in 1:length(outbreakunits)) {

 units[outbreakunits[j]] <- finalsize(reprratio,units[outbreakunits[j]]) #with all units
with                                                #an outbreak, the seroprevalence
changes
```

```
      }

    }

  }

  loglik <- 0                            #starting the loglikelihood calculation with value
0

  for(i in 1:length(dataN)) {            #for each herd in the dataset...

loglik <- loglik + log(sum(dbinom(dataX[i],dataN[i],units))/nrunits)  #...the log-
probability

               #of the observed outbreak is calculated, by averaging the probability over

                # all possible underlying 'true seroprevalences', as found in the simulated
               # seroprevalence distribution.

  }

  plot(sort(units,decreasing=T),type="l")   #the simulated distribution is plotted

  points((1:length(dataN) -
.5)*nrunits/length(dataN),dataX/dataN,col="red",pch=21,bg="red")

                       #the data are plotted on the same scale (X-axis) as the distribution

 loglik                 #the log-likelihood is printed on the screen

}

# example of dataset (from CLM sero-prevalence data)

       nseries <- c(101,151,75,76,104,112,218,98,129,45,75,97,106,156,75,120,114,45,90,

         60,91,90,153,75,162,60,60,60,45,60,90,45,30,95,75,75,75,75,77,150,13)

       xseries <- c(53,76,37,36,45,43,83,37,41,10,15,16,15,21,9,14,11,4,8,5,7,7,

         9,4,8,2,2,2,1,1,1,0,0,0,0,0,0,0,0,0,0)

#example of simulation with lamda = 0.02, R0 = 1.5, omega =0.1, dataN = nseries, dataX =
#xseries, nrunits = 1000 and nrmonths = 2000)

       loglikapprox(.02,1.5,.1,nseries,xseries,1000,2000)
```

Appendix 5.3. Stochastic SIR model

```
##'simulateoutbreak' simulates a single outbreak with an individual-based simulation
##until the outbreak is over. The time unit is one day, and every day the numbers
##of susceptible, infectious, and immune individuals are stored in "outbreaklist".
##At the end, the number of infectious is plotted against time, and the full dynamics
##is returned in a table.
##Parameters are phi (=per capita birth rate), mu (=natural death rate), muX
##(=FMD-related death rate), R0 (=basic reproductive ratio), ga (=recovery rate),
##om (=rate of loss of immunity), Z0 (=initial number of immunes), N (=population size)
simulateoutbreak <- function(mu, muX, R0, ga, om, Z0, N, tmax) {
        Xcur <- N-Z0-1
         Ycur <- 1
         Zcur <- Z0
         timecur <- 0
         outbreaklist <- c()
         cum_inc_cur <- 0
         cum_FMDdeaths_cur <- 0
         cum_nonFMDdeaths_cur <- 0
         while(Ycur > 0 && timecur < tmax) {
           Xout <- rbinom(1,Xcur,1-exp(-R0*(ga+mu+muX)*Ycur/(Xcur+Ycur+Zcur)-mu))
           Yout <- rbinom(1,Ycur,1-exp(-ga-mu-muX))
           Zout <- rbinom(1,Zcur,1-exp(-om-mu))
           newinf <- rbinom(1,Xout,1-mu/(mu+R0*(ga+mu+muX)*Ycur/(Xcur+Ycur+Zcur)))
           newrec <- rbinom(1,Yout,ga/(ga+mu+muX))
           newloi <- rbinom(1,Zout,om/(om+mu))
           deathsFMD <- rbinom(1,Yout-newrec,muX/(mu+muX))
           deathsnonFMD <- Xout + Yout + Zout - newinf - newrec - newloi - deathsFMD
           births <- deathsFMD + deathsnonFMD
           timecur <- timecur + 1
```

```
      Xcur <- Xcur + births + newloi - Xout

      Ycur <- Ycur + newinf - Yout

      Zcur <- Zcur + newrec - Zout

      cum_inc_cur <- cum_inc_cur + newinf

      cum_FMDdeaths_cur <- cum_FMDdeaths_cur + deathsFMD

      cum_nonFMDdeaths_cur <- cum_nonFMDdeaths_cur + deathsnonFMD

      outbreaklist <- c(outbreaklist,timecur,Xcur,Ycur,Zcur,

                        cum_inc_cur,cum_FMDdeaths_cur,cum_nonFMDdeaths_cur)

    }

    dim(outbreaklist) <- c(7,length(outbreaklist)/7)

    plot(t(outbreaklist[c(1,3),]))

    t(outbreaklist)

  }

  ##'simulatemultipleoutbreaks' simulates 'nr' outbreaks

  simulatemultipleoutbreaks <- function(mu, muX, R0, ga, om, Z0, N, tmax, nr) {

    multoutbrlist <- c()

    for(i in 1:nr) {

      singleoutbr <- simulateoutbreak(mu, muX, R0, ga, om, Z0, N, tmax)

      singleoutbr <- c(rep(i,length(singleoutbr)/7),singleoutbr)

      dim(singleoutbr) <- c(length(singleoutbr)/8,8)

      multoutbrlist <- c(multoutbrlist,t(singleoutbr))

    }

    dim(multoutbrlist) <- c(8,length(multoutbrlist)/8)

    tobereturned<-data.frame(t(multoutbrlist))

    names(tobereturned) <- c("simnr","day","X","Y","Z","Cum inc","Cum FMD deaths","Cum
nonFMD deaths")

    tobereturned

  }

# example of simulation of 1000 outbreaks (nr =1000) each for 500 days using the model
#parameters of the CLM system

  simulatemultipleoutbreaks(.000247,0.006667,1.48,.222,0.052/30,19992,119000,500,1000)
```

Chapter 6

Economic Modelling of the Impact of Foot and Mouth Disease and Its Control in Ethiopia

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Under review in *Preventive veterinary medicine* journal

Abstract

Foot and mouth disease (FMD) occurs endemically in Ethiopia. Quantitative insights on its national economic impact and on the economic feasibility of control options are, however, lacking to support decision making in its control. The objectives of this study were, therefore, to estimate the annual cost of FMD in cattle production systems of Ethiopia, and to conduct an *ex ante* cost-benefit analysis of potential control alternatives. The annual costs of FMD were assessed based on production losses, export loss and control costs. The total annual costs of FMD under the current status quo of no official control were estimated at 1,354 (90% CR: 864-2,042) million birr. The major cost (94%) was due to production losses. The cost-benefit of three potential control strategies: 1) ring vaccination (reactive vaccination around outbreak area supported by animal movement restrictions, 2) targeted vaccination (annual preventive vaccination in high risk areas plus ring vaccination in the rest of the country), and 3) preventive mass vaccination (annual preventive vaccination of the whole national cattle population) were compared with the base line scenario of no official control. Experts were elicited to estimate the influence of each of the control strategies on outbreak incidence and number of cases per outbreak. Based on these estimates, the occurrence of the disease was simulated by a stochastic model for 10 years. Preventive mass vaccination strategy was epidemiologically the most efficient control strategy by reducing the national outbreak incidence below 5% with a median time interval of 3 years, followed by target vaccination strategy with a corresponding median time interval of 5 years. On average, all evaluated control strategies resulted in positive net present values. The ranges in the net present values were, however, very wide, including negative values. The targeted vaccination strategy was the most economical strategy with a median benefit cost ratio of 4.29 (90%CR: 0.29-9.63). It was also the least risky strategy with 11% chance of a benefit cost ratio of less than one. The study indicates that FMD has a high economic impact in Ethiopia. Its control is predicted to be economically profitable even without a full consideration of gains from export. The targeted vaccination strategy is shown to provide the largest economic return with a relatively low risk of losses. More studies to generate data, especially on production impact of the disease and effectiveness of control measures are needed to improve the rigor of future analysis.

Key words: control, cost-benefit, economic, Ethiopia, foot and mouth disease, vaccination

6.1 Introduction

Foot and mouth disease (FMD) is considered as the most economically important disease of livestock due to its impact on livestock production and international trade (James and Rushton, 2002). The disease is highly transmissible, making it difficult to contain within local and national borders. With ever greater international interconnectedness, management of the disease is increasingly problematic. This implies that FMD is not only a constant problem in endemically infected countries, but also a constant threat to FMD free countries through sporadic disease incursions from endemic countries. Its control, therefore, generates an international public good and has led to a global initiative launched by FAO and OIE to progressively control FMD in the world (FAO and OIE, 2012).

Despite the recognition of FMD as the most important livestock disease in the world, the economic return from its control is not always positive in all countries (Knight-Jones and Rushton, 2013). In FMD free countries, control of outbreak incursions involves huge costs (0.3-0.6% of GDP), but generates positive returns to the national economy (Knight-Jones and Rushton, 2013). In endemic countries, the cost effectiveness of control depends on the prevailing production systems and the export potential of the country. Economic returns from FMD control are considered more beneficial to commercial production systems than to subsistence systems (Perry et al., 2003; Rushton, 2009, 2008). Moreover, in countries with limited export, the control has to be targeted to high risk regions or sectors to generate positive economic returns (Knight-Jones and Rushton, 2013).

In Ethiopia, FMD is endemic causing production losses and hampering international trade in animals and animal products. The Ethiopian government has a strong interest to control and reduce the current impact of FMD on production, and export trade in live animals and meat (Thomson, 2014). National animal disease control requires large investments and major resource allocations. As FMD control generates significant public goods, government involvement is justified by adopting the most economically efficient control policy. Given that the dominant livestock system in Ethiopia is subsistence oriented, and the complexity of the FMD epidemiology due to the presence of multiple hosts and virus types, the expected benefits from FMD control investments are difficult to determine in a straightforward manner.

There are varieties of economic analysis tools that can be used in evaluating the merits of alternative disease control policies to support economically efficient decision making (Bennett, 1992; Rich et al., 2005; Rushton and Thornton, 1999). Cost-benefit analysis is one of the economic models of choice in the assessment of livestock disease control polices at national level (Dijkhuizen and Morris, 1997; Rushton and Thornton, 1999; Rushton, 2009). Cost-benefit analysis is a method for organising information to support decisions about the allocation of resources. It is used to decide whether a proposed project or program should be undertaken, whether an existing project or program should be continued, or to choose between alternative projects or programs (Commonwealth of Australia, 2006). When it is used at national level disease control, it measures and compares the benefits and costs of alternative disease control programs.

Quantitative insights on the national economic impact of FMD on the current Ethiopian situation and on the economic feasibility of potential control options are lacking, despite its importance to support decisions on future national FMD control programs. The objectives of the current study were, therefore, to estimate the annual national costs of FMD, and to conduct an *ex ante* cost-benefit analysis of potential control alternatives in Ethiopia.

6.2 Background

Ethiopia has a large FMD susceptible livestock population consisting of about 54 million cattle, 25.5 million sheep and 24 million goats (CSA, 2013). Among these species of ruminants, FMD is clinically and economically more important in cattle. Therefore, the economic importance of the FMD in Ethiopia is primarily related to cattle and hence this study focuses on the impact of FMD on the cattle production.

6.2.1 Cattle population and production systems in Ethiopia

The latest estimate of the size of the cattle population in the sedentary and most pastoral rural areas of Ethiopia is approximately 54 million (CSA, 2013). When adjusted for cattle in the pastoral zones (based on proportion of the Afar and Somali cattle population estimated in MoRAD, 2007) and urban areas that are not covered by annual surveys of the Central Statistical Agency (CSA), the cattle population is estimated to be 57 million.

The production systems in which Ethiopian cattle are kept can be divided into three types. The dominant production system is the crop-livestock mixed (CLM) system which is mainly found in the central highland parts of the country. This system accounts for 80–85% of the national cattle population and occupies 40% of the land area (MoARD, 2007). Three quarters (542) of the 731[6] districts in the country have this type of production system with an average cattle population per district of approximately 79,455. In the CLM system cattle are owned by sedentary crop farmers, and are

6 The number of districts varies from time to time because merging and separation. The number referred here is based on the 2007 national population and housing census (CSA, 2008).

primarily used for draft power in crop cultivation. The second system is the pastoral[7] production system which is practiced in the arid and semiarid regions of Ethiopia. The pastoral system accounts for 15–20% of the cattle population and occupies 60% of the country area (MoARD, 2007). A quarter (169) of the Ethiopian districts has cattle predominantly in pastoral systems with comparable numbers of animals per district to those districts where the CLM system is dominant. In the pastoral system, livestock keeping is the main livelihood and cattle are used to produce milk for the family with surplus animals being sold to the market. The third system is the market oriented system whose contribution is small but growing and which is found in the urban and peri-urban regions of Ethiopia. This system produces milk and keeps improved breeds of cattle. The market oriented system is found in only 3% (20) of the districts and represents only around 0.5 million cattle, either of exotic breeds or their crosses. The average cattle population in market oriented districts was assumed to be around 25,000 head of cattle per district.

Livestock production in Ethiopia is predominantly focused on subsistence needs; market off-takes (percentage of livestock marketed) are relatively low. For example, the annual commercial gross cattle off-take rates are 16% and 11%; and the annual commercial net offtake rates (percent sold minus percent bought) are 8% and 9% in the CLM and pastoral systems, respectively (Negassa and Jabbar, 2008). But still livestock sales are an important source of cash income for the farming households and hard currency for national economy through export. Officially a quarter of a million heads of cattle were annually exported between 2010 and 2013 (Ethiopian Revenue and Custom Authority, 2014), although the illegal export of cattle is estimated to be four to six times the legal amount (GebreMariam et al., 2013). A majority (95%) of the livestock exported comes from the pastoral systems, predominantly from the Borena pastoral area in southern Ethiopia (Legese et al., 2008).

6.2.2 The FMD situation in Ethiopia

FMD is endemic in all production systems. Based on data over the years 2007 to 2012, annual district level incidence of FMD outbreak was estimated at 0.24, 0.39 and 0.85 per district year in the CLM, pastoral and market oriented dominated districts, respectively (Jemberu et al., 2015b). Outbreaks were reported to be caused by four serotypes of FMD virus: O, SAT 2, A and SAT 1 in order of the frequency of occurrence during the reported period. Whereas O and A are distributed throughout the country, SAT viruses are limited in the central and southern half of the country where 70% of the country's cattle population is found.

7 In the pastoral system includes also agro-pastoralists who drive part of their income from crop farming.

At the time of this study there was no official FMD control program in Ethiopia. The public veterinary service monitors FMD through the National Animal Health Diagnosis and Investigation Center. This activity includes irregular annual sero-monitoring, and outbreak investigation upon receipt of reports of suspected outbreaks. FMD vaccination is mainly practiced by farmers in the market oriented system, which could be a reactive vaccination in response to outbreaks or regular preventive vaccination (Beyi, 2012). FMD infected cattle are commonly treated with palliative antibiotics alongside traditional treatments in all types of production systems.

6.3 Materials and Methods

To estimate the total annual costs of FMD in Ethiopia, an economic impact assessment model was developed. The same model was subsequently used in the *ex ante* cost-benefit analysis of potential control alternatives.

The cost-benefit analysis consisted of the following consecutive steps. First, a set of feasible FMD control strategies was defined, followed by the development of an epidemiological model to simulate the course of the disease under the defined control strategies. In the next step, the epidemiological model was combined with the economic model developed for the cost estimation to calculate the incremental costs and benefits, and to determine the economic returns from the evaluated control strategies. Finally, to study the robustness of the results, sensitivity and breakeven analyses for economic returns were carried out.

6.3.1 Estimation of annual national costs of FMD

The annual economic impact of FMD was estimated based on the framework of Rushton (2009). According to this framework the economic impact of animal disease in an endemic situation can be classified as direct and indirect impacts as follows;

Direct impacts

a. Visible losses which include milk production loss, draft power loss, weight loss, and death loss.
b. Invisible losses which include fertility problems that lead to a change in herd structure and a delay in sale of animals and /or livestock products.

Indirect impacts

a. Additional costs which include control costs like the costs related to vaccination, movement restriction, diagnostic and surveillance, and costs related to the treatment of sick animals and the transaction costs of taking care of sick animals etc.

b. Returns foregone as a result of the use of less productive but disease resistant breeds, market disruption both local and international, loss of multiplier effects along the value chain etc.

Some of these cost categories are excessively difficult to estimate like the costs related to infertility problems which are often apparent only after an extended period. Other costs cannot be exclusively attributed to FMD due to the presence of other relevant diseases, like the loss of using less productive breeds to avoid the risk of FMD or the restriction on market accessibility. In this study, the annual costs of the disease were, therefore, modelled based on the most important and relatively easily quantifiable costs, including the costs related to production losses, control costs and export losses that are specifically attributed to the occurrence of FMD.

6.3.1.1 Annual production losses

Annual production losses were estimated based upon milk loss, draft power loss and mortality loss. These losses were separately stochastically estimated for the three production systems because of variations in cattle herd composition, the epidemiology of the disease and production coefficients among the production systems.

Total annual production losses (*PL*) at national level were modelled as an aggregate of milk loss, draft power loss and mortality loss within the three production systems as represented by

$$PL = \sum_i MilkL_i + DraftL + \sum_i MortL_i$$

Where $MilkL_i$ represents the annual economic loss due to milk loss within production system *i* with *i* = CLM, pastoral system or market oriented system, *DraftL* the annual economic loss due to draft loss within the CLM production system, and $MortL_i$ the annual economic loss due to mortality within production system *i*.

$MilkL_i$ is determined by

$$MilkL_i = Pop_i * Inc_i * Morb_i * (LCPropMorb_i - LCprop\ CF_i) * MilkLLC_i * Prmilk$$

Where Pop_i represents the population size of cattle, Inc_i the incidence rate of FMD outbreaks per year, $Morb_i$ the morbidity rate within an FMD outbreak, $LCPropMorb_i$ the lactating cow proportional morbidity[8] rate, $LCPropCF_i$ the lactating cow proportional

8 Proportional morbidity rate refers to the number of affected cattle in a specific category divided by the total number of affected cattle.

case fatality[9] rate, *MilkLLCi* the milk loss per affected lactating cow per outbreak in liters, and *Prmilk* the price of milk per liter.

DraftL is determined by

$$DraftL = Pop * Inc * Morb * (OxPropMorb - OxPropCF) * DraftLOx * Prdraft$$

Where *Pop* represents the CLM cattle population size, *Inc* the CLM incidence rate of FMD outbreak per year, *Morb* the morbidity rate in an outbreak of FMD in the CLM, *OxPropMorb* the ox proportional morbidity rate, *OxPropCF* the ox proportional case fatality rate, *DraftLOx* the draft loss per ox per outbreak in days, and *Prdraft* the price of draft power per day.

$ortL_i$ is determined by

$$MortL_i = (Pop_i * Inc_i * Morb_i) * ((AdPropCF_i * Prad_i) + (YSPropCF_i * PrYS_i) + (CfPropCF_i * PrCf_i))$$

Where $AdPropCF_i$ represents the adult cattle proportional case fatality rate, $Prad_i$ the price of adult cattle, $YSpropCF_i$ the young stock proportional case fatality rate, $PrYS_i$ the price of young stock, $CfPropCF_i$ the calf proportional case fatality rate, and $PrCf_i$ the price of a calf.

Cattle population data were primarily taken from CSA of Ethiopia (CSA, 2013). Information on outbreak incidences was used from Jemberu et al. (2015b). Data on the herd structure, morbidity and mortality, and production losses due to a FMD outbreak were based on the study by Jemberu et al. (2014) for the CLM and pastoral systems, and by Beyi (2012) for the market oriented system. Milk price and live cattle price data were based on the CSA monthly agricultural producer price survey of 2012 and 2013 (CSA, 2014). Draft power rent price was obtained from the field survey results of Jemberu et al. (2014). A detailed overview of the input data values is provided in Table 6.1.

9 Proportional case fatality rate refers to the number of cattle died in a specific category divided by the total number of affected cattle.

Table 6.1. Input data to estimate production losses due to FMD in Ethiopia

Input data	Values / distributions	Description and/or source
Cattle population	Point estimates; CLM = 43,064,610 Pastoral = 13,427,895 MO = 500,000	Derived from CSA annual survey (CSA, 2013) and MoARD (2007).
Proportion of lactating cows	Point estimates; CLM = 0.1887 Pastoral = 0.2222 MO = 0.4177	Based on Jemberu et al. (2014) for CLM and Pastoral, and Beyi (2012) for MO.
Incidence of FMD outbreaks per year	Binomial (n, p); CLM (542, 0.24) Pastoral (169, 0.39) MO (20, 0.85)	*n* equals the number districts and, *p* is the average probability of outbreak occurrence, based on Jemberu et al. (2015b).
Morbidity rate in an outbreak	Binomial (n, p) CLM (79455, 0.31) Pastoral (79455, 0.45) MO (25000, 0.12)	*n* equals the number of cattle per district and *p* is the morbidity rate of FMD in an outbreak based on Jemberu et al. (2014) for CLM and Pastoral, and on Beyi (2012) for MO.
Proportional morbidity rate of lactating cows	Point estimates; CLM = 0.2136 Pastoral = 0.2334 MO = 0.3508	Based on Jemberu et al. (2014) for CLM and Pastoral, and on Beyi (2012) for MO.
Proportional morbidity rate of oxen	Point estimate; CLM = 0.3128	Based on Jemberu et al. (2014).
Proportional case fatality rate of lactating cows	Point estimates; CLM = 0.000765 Pastoral = 0.000731 MO = 0.017323	Based on Jemberu et al. (2014) for CLM and Pastoral, and on Beyi (2012) for MO.
Proportional case fatality rate of oxen	Point estimate; CLM = 0.002555	Based on Jemberu et al. (2014).
Proportional case fatality rate of adult cattle	Point estimates; CLM = 0.00332 Pastoral = 0.002251 MO =0.026094	Based on Jemberu et al. (2014) for CLM and Pastoral, and on Beyi (2012) for MO.

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Proportional case fatality rate of young stock cattle	Point estimates; CLM = 0.005178 Pastoral = 0.000333 MO = 0.01206	idem
Proportional case fatality rate of calves	Point estimates; CLM = 0.023497 Pastoral = 0.009404 MO =0.041502	idem
Milk loss per FMD affected cow (liters)	Fitted distributions truncated at 0; CLM = InvGaus (73.23, 240.34, shift(-14.33)) Pastoral = Gamma (5.65,8.21, shift (6.3)) MO = Normal(159, 37)	idem
Draft power loss per affected ox (days)	Laplace (4.98, 2.38) truncated at 0	Based on Jemberu et al. (2014)
Average price of milk ([a]birr/liter)	Triangular (6.67,10,14)	Based on CSA producers monthly price survey (CSA, 2014)
Price of draft power of an ox (birr/ day)	Triangular (30,50,100)	Based on Jemberu et al. (2014)
Price of adult cattle (birr/head)	Triangular (a, b, c); CLM= (2100,3200,7700) Pastoral= (2100,3200,7700) MO = (8000,10000,12000)	Based on CSA producers monthly price survey for CLM and Pastoral (CSA, 2014) and field survey for MO
Price of young stock (birr/head)	Triangular (a, b, c); CLM = (1400, 1600, 5200) Pastoral=(1400, 1600, 5200) MO = (4000,6000,8000)	idem
Price of calves (birr/head)	Triangular (a, b, c); CLM = (500,1200,3100) Pastoral = (500,1200,3100) MO = (1500,3000,4500)	idem

CLM = Crop-livestock mixed production system; Pastoral = Pastoral production system; MO = Market oriented production system.

[a]Birr is Ethiopian currency; 1 birr = 0.05 USD.

6.3.1.2 Annual export losses

Despite its potential, Ethiopia has currently no access to premium live animal and meat markets because of the presence of FMD. However, FMD specific impact on export is difficult to estimate as on the one hand FMD is not the only disease that restricts access to premium export markets and on the other hand the export bans by non-free importing countries are not always associated with immediate outbreaks and are therefore unpredictable. For this reason only the regular and exclusive export impacts of FMD, which are associated with the rejection of FMD sero-positive export destined cattle, were estimated. Cattle destined for export are serologically tested for FMD and sero-positives are rejected from the export consignment and sold in the domestic market. Annual export losses (*EL*) were, therefore, deterministically estimated based on the average number of animals rejected from export and the difference between export price (subtracting transport cost) and domestic price.

$$EL = NEDC * PSPC * (EP - DP - TC)$$

Where *NEDC* represents the average number of export destined cattle per year, *PSPC* the proportion of sero-positive cattle, *EP* the free on board export price of cattle, *DP* the domestic price of cattle, *TC* the transport cost from feedlot to export port.

The average number of exported cattle per year was derived from four years (2010-2013) of export data obtained from Ethiopia's revenue and custom authority (Ethiopian Revenue and Custom Authority, 2014). The free on-board price of export cattle, transport costs from fattening sites to the export port and the price of rejected export destined cattle in the local market were obtained by interviewing cattle exporters. The proportion of export destined cattle rejected because of sero-positivity for FMD was derived from three years (2010-2012) of data from National Veterinary Institute (NVI). Details of the data and their sources are provided in Table 6.2.

Table 6.2. Input data for the estimation of annual export losses due to FMD in Ethiopia

Input data	Values	Description and/or Source
Annual number of export destined cattle	257 408	Ethiopian revenue and custom authority (Ethiopian Revenue and Custom Authority, 2014)
Rejection rate of export destined animals (FMD sero-positive proportion)	0.06	Based on NVI record of serological test results of export destined animals
Free on board export cattle price (birr)	12 600	Exporters' information
Domestic price of export rejected animals (birr)	10 000	idem
Transport cost to export port (birr)	350	idem

6.3.1.3 Annual FMD control costs

Disease control costs are those costs incurred to gather information for designing and implementing control measures, for containing or preventing occurrence of an outbreak and for treatment of affected animals to lessen the impact of illness. These control costs were deterministically estimated based on average national costs related to disease surveillance (sero-monitoring, outbreak investigation), vaccination and treatment.

$$CC_i = NCSM * CSM + NOBI * COBI + NCV * CV + NCT * CT_i$$

Where CC_i represents annual control costs within production system i, *NCSM* the number of cattle covered by sero-monitoring, *CSM* the costs of sero-monitoring per head of cattle, *NOBI* the number of outbreaks investigated per year, *COBI* the costs of an outbreak investigation, *NCV* the number of cattle vaccinated per year, *CV* the cost of vaccination per head of cattle, *NCT* the number of FMD affected cattle treated per year, and CT_i the costs of treatment per head of cattle.

The number of animals covered by sero-monitoring and the number of outbreaks investigated per year were derived from three years (2011-2013) of outbreak data obtained from the National Animal Health Diagnostic and Investigation Center (NAHDIC), a governmental institute mandated for surveillance and diagnosis of transboundary diseases in Ethiopia. The number of animals vaccinated annually was estimated from the vaccine sale volume of NVI, which is the only institute that produces and imports FMD vaccines in the country. The proportion of FMD affected animals that were treated by antibiotics was estimated from a field survey (Jemberu et al., 2014). The costs of FMD tests for the sero- monitoring and the price of vaccine were obtained from NVI. Costs of outbreak investigations, delivery of vaccination, and antibiotic treatments were based on a field survey (Jemberu et al., 2014). Details of the control cost data and their sources are provided in Table 6.3.

Table 6.3. Input data for the estimation of annual control costs based on the current FMD situation in Ethiopia

Input data	Values	Description and/or Source
Annual number of cattle vaccinated under the current situation	331,400	Based on NVI annual vaccine sale data
Proportion of treated FMD infected cattle	CLM = 0.09 Pastoral = 0.30 MO = 0.83	Jemberu et al., 2014
Palliative treatment cost per infected animal (birr)	CLM = 25 Pastoral = 25 MO =100	Jemberu et al., 2014
Annual number of sera tested for FMD monitoring under the current situation	2 779	Based on NAHDIC disease surveillance database
Cost of sero-testing for FMD including sample collection (birr/sample)	45	The price of test (35 birr) is based on NVI price of NSP tests, and sampling cost (10 birr) based on author's judgment
Outbreak investigation cost (birr)	30 350	Authors' calculation

CLM = Crop-livestock mixed production system; Pastoral = Pastoral production system; MO = Market oriented production system.

6.3.2 Cost-benefit analysis of FMD control

A cost-benefit analysis was performed for a set of proposed alternative FMD control strategies using the current control situation as the baseline scenario. The proposed alternative control strategies, the epidemiological model predicting the FMD situation under the alternative control strategies, and the determination of incremental costs and benefits associated with the control strategies are described in the following sub-sections.

6.3.2.1 Defining control strategies

Based on the expected feasibility of application within the Ethiopian situation, a set of FMD control strategies was defined to be evaluated. The control strategies were aimed to reduce the incidence of FMD outbreaks to the level of eliminating the endemicity. The minimal level of national outbreak incidence assumed to be feasible to be reached by the control measures was up to 5%. Further reductions were assumed to be infeasible in the short to medium term without drastic control measures such as strict animal movement control and culling of infected or in contact animals and harmonization of control with neighboring countries.

The control strategies were defined mainly based on the epidemiological information as documented by Jemberu et al. (2015b) and the FMD control plans as developed under auspices of the Ministry of Agriculture and Rural Development (MoARD, 2006) and the Food and Agriculture Organization of the United Nation (Thomson, 2014). The control strategies are centered on three alternative vaccination approaches, focused only on cattle. In mixed populations of cattle and sheep, there is both experimental (Bravo De Rueda et al., 2015) and field evidence (Sutmoller et al., 2003) that vaccinating only cattle is sufficient to control and even eradicate FMD.

The baseline control scenario reflecting the current situation and the three proposed alternative control strategies are described as follows.

i. No official control (baseline scenario)

This baseline scenario represents the current status quo of no official control except some vaccination by individual farmers, especially, in the market oriented production system. It is assumed that in all production systems the disease continues to occur with the historical trends as documented by Jemberu et al. (2015b).

ii. Ring vaccination strategy

The ring vaccination strategy (RVS) involves a rapid FMD outbreak detection and confirmation followed by a ring vaccination around the outbreak, and restrictions of animal and animal products movement within the infected district until the outbreak wanes. The ring vaccination is assumed to be applied to all non-infected cattle older than 4 months of age in the infected districts. The vaccination is assumed to be by a homologous vaccine based on the serotype identified.

iii. Targeted vaccination strategy

The targeted vaccination strategy (TVS) involves a preventive annual vaccination of all cattle in areas with high outbreak incidences (high risk areas) and reactive ring vaccination in the rest of the country as defined in the RVS. High risk areas targeted for annual preventive vaccination include: (1) urban and peri-urban centers which are characterized by market oriented livestock production; (2) areas within 5 km on both sides of the major cattle trade routes; and (3) the southern and southeastern pastoral areas. The targeted population consist of 0.5 million exotic and crossbred cattle in the market oriented system, 2.8 million cattle in the 5 km areas around the major livestock routes in the country[10], and 7 million pastoral cattle in the south and southeastern pastoral areas.

In the TVS strategy, preventive vaccination in the target areas is considered to be carried out two times at a 4-6 weeks interval at the start of the strategy, followed by an annual vaccination until the national incidence drops to 5% after which only ring vaccination (RVS) is applied to maintain the incidence at this level. Preventive vaccination is assumed to take place with a trivalent vaccine with matching field strains.

iv. Preventive mass vaccination strategy

For the preventive mass vaccination strategy (PMVS), it is assumed that all cattle above 4 months of age are vaccinated (blanket vaccination). Similar to TVS, an initial double vaccination with a 4-6 weeks interval is considered, followed by an annual vaccination until the incidence of the disease becomes less than 5% after which RVS is applied to maintain the incidence at this level. A trivalent vaccine is assumed to be used in the central and southern half of the country and a bivalent vaccine in the northern parts of the country. The vaccines are assumed to match with the circulating field strains.

6.3.2.2 Modelling the epidemiology of FMD

Spatially explicit herd based transmission simulation models are often used to study the evolution of FMD under alternative control measures in disease free developed countries (Bates et al., 2003; Durand and Mahul, 2000; Keeling et al., 2001; Martínez-López et al., 2010). Such sophisticated simulation models are not available for endemic FMD countries because of a lack of spatial and structural data on livestock farms, and animal movement data.

Given the difficulties of developing appropriate mathematical transmissions models, this study pragmatically represents the future outbreaks of FMD by its historical trend and utilizes a straightforward relationship between a control strategy and the resulting change in the FMD incidence over time as has been done in earlier studies on the impact of FMD control in endemic situations (Perry et al., 2003; Power and Harris, 1973; Randolph et al., 2002).

10 The 7 major routes from Addis Ababa to different directions into the country include: Bahir Dar-Gondar- Metema route, Dessie- Mekele route, Awash- Asayta Djibouti route, Adama-Harar-Jijiga-Berbera route, Hawassa-Moyale route, Jimama Gambela route and Nekemet-Asssosa route. An average distance per route of 800 km is assumed. A 5 km wide area along each sides of the route gives 800 km *7 routes* 10 km a total area of 56 000km^2 which is equivalent to 37 districts (average area of 1500km^2/district), or roughly 5% districts of the country and hence 5% of the national cattle population.

To account for the uncertainty and variation in incidence and disease control parameters, the epidemiological model was simulated stochastically. In the no official control (baseline) scenario, the FMD outbreak incidence is considered to continue in line with its historical trend in the three production systems (Jemberu et al., 2015b). The control strategies applied are assumed to decrease the incidence of FMD outbreaks annually by a certain percentage from the preceding year:

$$I_0 \rightarrow I_1 = I_0 a \rightarrow I_2 = I_1 a \rightarrow \cdots \rightarrow I_n = I_{n-1} a$$

Where *I* represents the yearly incidence of outbreaks, *n* years in the control period, → application of a control measure and *a* the percentage reduction in outbreak incidence as a result of the measure.

The decrease in the incidence of cases during an outbreak due to the application of a control strategy is modelled similarly. In ring vaccination, the reduction in case incidence in an outbreak is always considered in reference to the baseline, as there is no buildup of immunity through time:

$$C_0 \rightarrow C_1 = C_0 b \rightarrow C_2 = C_0 b \rightarrow \cdots \rightarrow C_n = C_0 b$$

Where *C* represents the case incidence during an outbreak, *n* years in the control period, → application of the ring vaccination control measure, and *b* the percentage reduction in case incidence.

In preventive vaccination there will be build up population immunity through time. Hence it is assumed that the case incidence in an outbreak decreases annually by a certain percentage from the preceding year:

$$C_0 \rightarrow C_1 = C_0 b \rightarrow C_2 = C_1 b \rightarrow \cdots \rightarrow C_n = C_{n-1} b$$

Where *C* represents the case incidence during an outbreak, *n* years in the control period, → application of the preventive vaccination control measure, and *b* the percentage reduction in case incidence.

The control parameters *a* (outbreak incidence reduction) and *b* (case incidence reduction) were obtained for each control strategy and production system through expert elicitation using an e-mailed questionnaire. The questionnaire provided a description of the Ethiopian livestock systems, the existing FMD situation and the proposed alternative control strategies to provide the context to the experts. The context description was followed by the questions to elicit the expected effectiveness of each proposed control strategy in reducing outbreak and case incidences in the different production systems. To account for uncertainties within the estimates, the questions were set to elicit the minimum, the most likely and the maximum likely percentage reductions in incidences. The questionnaire was sent to 15 FMD experts, selected for their experience of FMD in endemic situations or their experience in FMD modelling. Eight of these experts were contacted based on their published work on FMD, while the other seven experts were recruited by reference of the first selected experts (snowballing). Eight of the 15 experts completed the questionnaire. The others did not respond (four experts) or responded that they could not make the judgment (three experts). Information provided by three of the eight experts who completed the questionnaire was either incomplete or lacked logical consistency and was excluded from further analyses.

The judgments of the remaining five experts differed widely. Table 6.4 summarizes the ranges of the most likely values given by experts. Despite their differences in their judgments, they generally expected a relatively high effectiveness for PMVS, and a relatively higher incidence reduction in Market oriented system. Some experts expected RVS to have even a negative effect on the incidence reduction. Because of the widely different judgments, it was found inappropriate to linearly pool their judgments to define one overall probability distribution by averaging the parameter entries among experts (Keith, 1996; Morgan, 2014). The individual experts' pert probability distributions were, therefore, combined to a single composite distribution using a discrete uniform

Table 6.4. Ranges (min, max) of the most likely estimates of the experts for outbreak and case incidence reductions for the different control strategies in different production systems

Control strategy	Production system		
	CLM system	Pastoral system	Market oriented system
Outbreak reduction (%)			
RVS	(-10, 35)	(-10, 20)	(0, 50)
TVS	(5, 60)	(5, 50)	(10, 80)
PMVS	(10, 75)	(5, 75)	(35, 80)
Case reduction (%)			
RVS	(-10, 40)	(-10, 35)	(20, 70)
TVS	(0, 40)	(10, 60)	(25, 80)
PMVS	(0, 75)	(10, 65)	(25, 80)

probability distribution with equal weights as described by Vose (2008). To account for the correlation between the estimated parameters within experts the model uses parameters only from a single expert in a single iteration. Correlations between outbreak incidence and case incidence reductions could also be expected but based on the available information it was not possible to quantify them. We used a large number of iterations to partly account for these correlations. The complete overview of the experts' opinions is provided in Appendix 6.1.

6.3.2.3 Combining the epidemiological and economic models.

The described epidemiologic and economic models were combined to calculate the costs and benefits of each control strategy through time. The time horizon of the analysis was set at 10 year to be able to account for the future benefits of control strategies with high upfront costs. It is assumed that the total cattle population and distribution among production systems remain the same throughout the time horizon of the analysis.

The net returns of each of the strategies were assessed by estimating the incremental costs and benefits in relation to the base scenario through time. The net present value (NPV) and benefit cost ratio (BCR) were used as performance criteria.

The incremental benefits from control consisted of avoided production losses, treatment costs and export losses. Avoided production losses and treatment costs were calculated based on the total number of avoided FMD cases as predicted by the epidemiological model. Avoided export losses were based on the reduction in sero-prevalence, which was considered to be linearly related with the reduction in outbreak incidence in the pastoral production system which is main source of export animals.

The incremental costs of control were due to increased costs or revenues forgone. The increased costs were made to enable an effective implementation of the control strategy and consisted of increased surveillance, outbreak investigations, movement restriction enforcement, vaccination, post vaccination sero-monitoring, and staff capacity building. Details on the estimation of the control costs are provided in Appendix 6.2. A summary of the cost estimates are presented in Table 6.5.

Revenues foregone were consisted of a temporary decrease in milk yield due to vaccination and market losses due to movement restriction during outbreaks. Temporary milk reduction in vaccinated lactating cows are common and are caused by stress and/ or a systemic or local reaction against the antigens and adjuvants present in vaccines (Martinod, 1995). Even allergic reactions may occur in repeatedly FMD vaccinated cattle (Yeruham et al., 2001). No empirical data were, however, available regarding the extent of milk loss due to FMD vaccination. A loss of one day milk yield for each vaccinated cow was assumed in this study. Market losses as result of animal movement restriction could be another cause of revenues forgone. Given the dominantly subsistence nature

Table 6.5. Input data used in control cost estimations per production system and control strategy

Input data	Distribution and values	Description and/or source
Proportion of lactating cows	Point estimates; CLM = 0.19 Pastoral = 0.22 MO = 0.42	Based on Jemberu et al. (2014) for CLM and Pastoral, and on Beyi (2012) for MO.
Average daily milk yield of cows (liter/day)	Point estimates; CLM = 2.3, Pastoral = 2.2, MO = 13.2	Based on Jemberu et al. (2014) for CLM and Pastoral, and on Beyi (2012) for MO.
Costs of vaccine (birr/dose)	Triangular (a,b,c,); monovalent (5,10, 15) bivalent (7,13,19) trivalent(8,16,24)	The most likely values were based on the price of imported trivalent vaccine quoted by NVI in 2013. The minimum and maximum were set by varying 50% from the most likely values.
Costs of vaccine delivery (birr/animal)	2	[a]Authors' estimation
Costs of outbreak investigation (birr/outbreak)	30 350	idem
Costs of movement restriction enforcement (birr/outbreak)	36 000	idem
Costs of cold storage (birr)	RVS = 17 061 540	idem
	TVS = 19 444 600	idem
	PMVS = 29 240 000	idem
Costs of sero-monitoring		
(birr/outbreak)	RVS = 42 350	idem
(birr/year)	TVS = 502 425	idem
(birr/year)	PMVS = 1 522 500	
Costs of surveillance (birr/year)	825 826	idem
Staff capacity building (birr)	5 000 000	idem
Discounting factor (%)	10	Zhuang et al. (2007)

CLM = Crop-livestock mixed production system; Pastoral = Pastoral production system; MO = Market oriented production system. RVS = ring vaccination strategy, TVS = targeted vaccination strategy; PMVS = preventive mass vaccination strategy

[a]The details of authors' estimation of various control costs are provided in Appendix 6.2

of the livestock production, however, the market loss would be minimal and hence was ignored.

The 2013 price levels were used for all costs and benefits in the analysis period. The incremental costs and benefits in different years of the time horizon were discounted to correct for the decreasing value of money over time. A 10% social discount rate (Zhuang et al., 2007) was used to discount future benefits and costs to present values.

In the estimation of incremental costs and benefits, the market (price) effect of controlling FMD was assumed negligible. This assumption was made primarily based on the fact that most of the production will occur in the subsistence systems and any increase in production may not necessary come to the market as an increased supply. The other reason to ignore the market effect was due to the lack of relevant data such as demand and supply price elasticities for products affected by control.

6.3.2.4 Simulation

The stochastic model was created in Microsoft Excel with the add-in @Risk software (Palisade Corporation (2013), Ithaca NY, USA). Key epidemiological inputs (outbreak and case incidences), control impact inputs (outbreak and case reductions), most economic inputs (yield losses, prices, and control costs) were supplied in the form of distributions rather than point estimates to account for random variations and uncertainties within the inputs. The Latin hypercube sampling method was used to sample values from input distributions. Each simulation was run for 100,000 iterations, which was sufficient to produce a stable output distribution as indicated by less than 1 % variability in the relevant output from repeated simulations.

6.3.2.5 Sensitivity and breakeven analyses

The impact of uncertainty and variation in inputs on the BCR of control strategies was assessed using the in-built sensitivity analysis of @Risk. The sensitivity analysis was carried out using Spearman rank correlation as relationship between some inputs and outputs of the cost-benefit analysis was nonlinear. A breakeven analysis was carried out for those input parameters to which the BCRs of the control strategies were most sensitive by varying the value of the parameter under investigation, while keeping the values other parameters at their mean values. A breakeven value is the mean value of a parameter that makes the BCR equal to unity.

6.4 Results

6.4.1 Annual costs of FMD in Ethiopia

The total annual costs of FMD in Ethiopia under the status quo were estimated to be 1,354 (90% central range (CR) 864-2,042) million birr (Table 6.6). Most of the costs (94%) were attributed to production losses. The CLM system accounted for the majority of losses with a share of 69% of the total annual costs followed by the pastoral system (26%). Despite differences in the absolute proportions among production systems, milk losses constituted the majority of costs in all production systems (Table 6.6).

Almost all of the costs were incurred by the private sector in which the producers suffered 97% of the total costs due to production losses, vaccination costs and treatment costs, and traders incurred 3.0 % due to export losses. Under the status quo, the public sector incurred only less than 0.1% of the total costs which is related to disease surveillance.

Table 6.6. The total annual costs of FMD in Ethiopia by cost category and production system (in million birr[a])

Cost category	National		CLM system		Pastoral system		Market oriented system	
	Mean (90% CR)	%TC	Mean (90% CR)	% TC	Mean (90% CR)	% TC	Mean (90% CR)	% TC
Production loss	**1,270 (783-1,958)**	**93.79**	**932 (493-1584)**	**99.00**	**286 (125-519)**	**81.27**	**53 (36-71)**	**84.86**
Milk loss	665 (278-1,268)	49.12	412 (87-989)	43.77	225 (69-454)	64.02	28 (15-44)	46.01
Draft power loss	308 (95-589)	22.77	308 (95-586)	32.76	n.a[b].	n.a.	n.a.	n.a.
Mortality loss	297 (216-393)	21.89	212 (136-304)	22.55	60 (37-90)	17.26	24 (18-30)	38.85
Export Loss	**40 (34-46)**	**2.98**	**n.a.**	**n.a.**	**40 (34-46)**	**11.41**	**n.a.**	**n.a.**
Control cost	**44 (38-50)**	**3.23**	**8.42 (7.16-9.74)**	**0.09**	**25.78 (20-31)**	**7. 32**	**9.39 (8-10)**	**15.14**
Vaccination cost[c]	4.97 -[d]	0.37	n.a.	n.a.	n.a.	n.a.	4.97 -	8.02
Monitoring cost	0.13 -	0.01	0.09 -	0.01	0.029 -	0.01	0.004 -	0.01
Outbreak investigation cost	1.49 -	0.11	1.10 -	0.12	0.342 -	0.10	0.045 -	0.07
Treatment cost	37 (31-43)	2.74	7.21 (6-9)	0.79	25.40 (20-31)	7.22	4.36 (3-5)	7.04
Total cost (TC)	**1,354 (864-2,042)**	**100**	**940 (501-1,593)**	**100**	**352 (187-588)**	**100**	**62 (44-81)**	**100**

[a] 1 birr = 0.05 USD

[b] n.a. = not applicable

[c] The majority of vaccination occurs in the market oriented system, all vaccine cost are therefore ascribed to this system.

[d] Values without CR are deterministically derived.

6.4.2 Evaluation of alternative FMD control strategies

6.4.2.1 Epidemiological performance

Based on the epidemiological model, PMVS was expected to be epidemiologically the most efficient strategy followed by TVS. The median years of control by which the targeted national outbreak incidence level (<5%) could be reached were about 3 years, 5 years and > 10 years for PMVS, TVS and RVS, respectively (Figure 6.1).

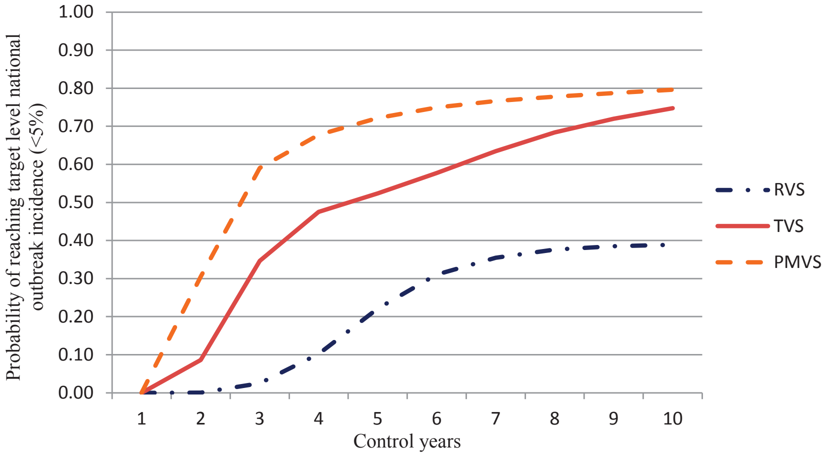

Figure 6.1. The probability of reaching the targeted level (<5%) of national FMD outbreak incidence during the control period under the different control strategies.

6.4.2.2 Economic performance

The different control strategies had different scales and distributions of benefits and costs during the analysis period (Figure 6.2). Because of the skewedness of the distribution of costs and benefits, medians are used to represent the output distributions. The RVS needs a relatively modest investment of few hundred million birr to begin the control compared to the PMVS which needs billions of birr in the initial years of the control. Whereas RVS and TVS have a positive net return starting from the first year of control, PVMS would need five years for the net return to become positive i.e. the payback period would be after five years.

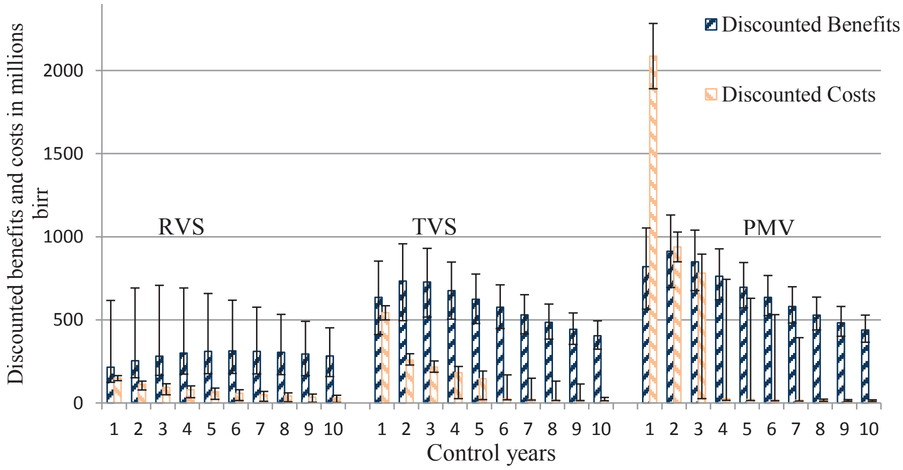

Figure 6.2. Discounted benefits and costs of the control strategies during the control period. The main bars represent median values while the error bars represent interquartile ranges.

The economic performance of the alternative control strategies over the 10 years of simulation is presented by the corresponding NPVs and CBRs in Tables 6.7 and 6.8. All the three control strategies resulted in average positive NPVs indicating that they are, on average, economically viable. However the ranges in NPVs are very wide and include negative values which indicate a risk of loss in all evaluated control strategies (Table 6.7).

Table 6.7. The distributions of the 10 years NPVs for different control strategies (in billion birr)

Strategy	Mean	5^{th} percentile	Median	95^{th} percentile	Probability of NPV<0
RVS	1.74	-9.96	2.08	8.69	0.20
TVS	4.11	-1.94	4.45	8.73	0.11
PMVS	2.03	-4.40	2.51	7.11	0.25

TVS was the most cost effective strategy with a median BCR of 4.29 i.e. for one birr invested, it would pay about 4 birr in return (Table 6.8). TVS also had the highest median NPV and the lowest probability of resulting in a loss (Table 6.7). RVS resulted in a median BCR of 3.73, while the median BCR of PMVS equaled 1.63. The range of BCR values of RVS includes negative values indicating that its implementation could result in even negative returns.

Table 6.8. Distributions of the 10 year BCRs of different control strategies

Strategy	Mean	5th perecentile	Median	95th percentile	Probability of BCR<1
RVS	9.02	-5.66	3.73	31.73	0.20
TVS	4.52	0.29	4.29	9.63	0.11
PMVS	1.69	0.47	1.63	3.23	0.25

The cumulative distributions of BCRs of the control strategies in presented in Figure 6.3. The cumulative BCR distribution curve of RVS shows three distinct sections corresponding to three clusters of expert judgments about the effectiveness of this strategy (Figure 6.3). The judgments of the experts for the effectiveness of other strategies were relatively less divergent, resulting in smooth cumulative distribution curves (Figure 6.3).

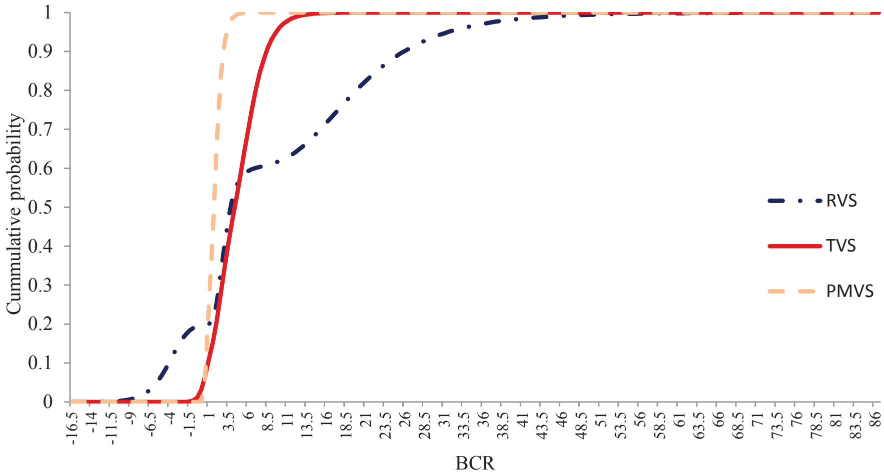

Figure 6.3. Cumulative distributions of BCRs of the control strategies

The net returns of the control strategies varied between the different production systems. The most cost effective strategy for CLM was TVS. For the pastoral and market oriented systems the most cost effective strategy was RVS (Table 6.9). However, it must be noted that there are interactions between the systems in terms of control strategies especially in the case of TVS. The indicated BCRs may, therefore, not necessary reflect the economic return if control strategies are applied in isolation within each of the production systems.

Table 6.9. BCRs of the nationally implemented control strategies in the different productions systems

Productions system	Control Strategy	Mean	5th percentile	Median	95th percentile	Probability of BCR <1
CLM	RVS	11.63	-5.71	4.05	44.54	0.21
	TVS	9.83	-0.07	8.39	24.51	0.09
	PMVS	1.62	0.33	1.51	3.38	0.29
Pastoral	RVS	7.80	-8.44	4.82	33.14	0.23
	TVS	2.19	0.25	2.08	4.52	0.17
	PMVS	1.82	0.60	1.65	3.66	0.21
Market oriented	RVS	7.39	0.34	3.29	25.30	0.16
	TVS	2.26	1.18	2.02	3.96	0.01
	PMVS	2.73	1.21	2.75	4.54	0.01

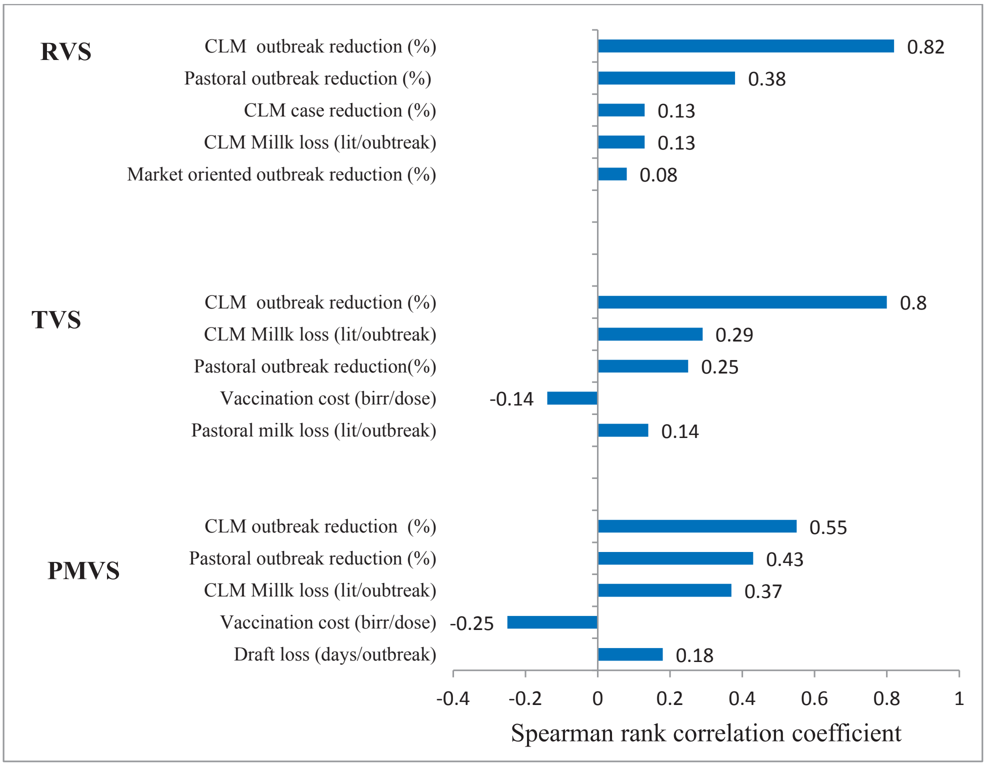

Figure 6.4. Input parameters to which the BCR of the control strategies were most sensitive as indicated by the Spearman rank correlation coefficient.

6.4.3 Sensitivity analysis and break even analyses

The top five input variables, to which the BCRs of the three control strategies were most sensitive, based upon Spearman rank correlation coefficients, are given Figure 6.4. BCR is most sensitive to CLM outbreak incidence reductions in all strategies in which it had a correlation coefficient greater than 0.5. Other inputs of which the variations show relatively high correlation with BCRs include milk losses in all systems, and vaccination costs in TVS and PVMS.

As the outbreak incidence reduction parameter was the input variable to which the BCR was most sensitive and its value was derived from expert opinion rather than empirical evidence, a breakeven analysis was performed. Assuming the same level of reduction in outbreak and case incidences in all production systems, the breakeven values for this input parameter were about 2%, 6% and 25% for RVC, TVS, and PVMS, respectively.

6.5 Discussion

In this study we estimated the total annual costs of FMD in Ethiopia, and analyzed potential economic benefits of its control for the first time. The analysis is done by using a stochastic modelling approach which generates a range of model outputs that give insights about variability in the outputs related to the uncertainty and variability of the input parameters used in the analysis.

6.5.1 Total annual costs of FMD in Ethiopia

The cost estimation under the current Ethiopian FMD situation showed considerable total costs that represent approximately 0.14% of the gross domestic product (GDP) of Ethiopia in 2013 (World Bank, 2015). This GDP proportion is slightly higher than the 0.10% estimate for Africa that was made based the annual FMD loss estimates of Knight-Jones and Rushton (2013). The current estimated costs of the disease can be considered conservative as it excludes some costs of the disease such as reproductive loss, loss of condition in fattening animals, losses related to chronic forms of the disease, losses in small ruminants, and indirect costs such as use of suboptimal technology due to fear of the disease. Some of these costs were excluded because of lack of reliable data. For example, FMD is known to have a chronic form that has significant economic impact on the affected animals (Barasa et al., 2008; Bayissa et al., 2011), but no information was available about its incidence during outbreaks. No chronic FMD was encountered or mentioned by farmers during the field outbreak investigation done in earlier study (Jemberu et al., 2014). Loss of condition due to FMD could be an important economic impact for feedlots. This effect has not been considered due to a lack of demographic and economic data about feedlots in Ethiopia. It can, however, be safely assumed that feedlots represent only a very small proportion the livestock system and their exclusion will have a minor effect on the national cost estimate.

When the costs are broken down by production system, the CLM system constitutes the largest share. This is more a reflection of its large cattle population than the severity of impact of the disease in this system. Proportionally, the market oriented system suffers the most by incurring 4% of the total costs, while the system accounts for less than 1% of the national cattle population. This is related to a high yield loss per affected animal and high costs of control as currently applied in this production system.

Milk losses were the major cost component in all production systems and constitutes about half of the total annual costs of FMD in Ethiopia. Draft power losses are the second most important economic impact, accounting for about one third of the total national costs in the CLM system and close to a quarter of the total national costs. Most production losses were associated with morbidity. Although the full export cost of the disease was not considered, the regular export losses associated with FMD were relatively moderate. The export of cattle or beef in Ethiopia is currently more constrained by price competiveness, both domestically and internationally, than sanitary problems such as FMD (GebreMariam et al., 2013). Also for the established export destinations in the middle east, the binding constraint is more the result of high domestic input cost than of sanitary requirements (Rich et al., 2009).

An important aspect of this FMD costs estimate is that due to the subsistence nature of the main production systems, all the production losses quantified in financial terms are not fully financial income losses to the farmers. For those farmers the costs of production losses would be mainly in terms of quantity or quality losses of food for the household due to a lower milk and/or crop yield. The consequence is a lower food or nutrition security.

6.5.2 Economic returns to control

The cost-benefit analysis of different control strategies needed an epidemiological model that simulates the impact of control strategies on future evolution of the disease. In this study, the impact of the proposed control strategies on the incidence of FMD was simulated based on the assumption of a simple relationship between control measures and disease incidence. It was assumed that control measures will have the same relative impact on the disease incidence year after year. As a result, the incidence progressively decreases until the preset minimum threshold was reached. The impact of the control in the disease incidence was derived from expert opinions. This approach simplifies the complex relationship between control measures and disease transmission which is influenced by several factors like contact structure of the population, demographic dynamics, disease surveillance and response capacity. Ideally, the simulation on the course of the disease should be done by spatially explicit transmission modeling that better represents the reality and is parameterized by empirical data. Data requirements for such complex models are high, while these data are virtually nonexistent under the current situation of Ethiopia's livestock production system. The applied approach is considered as the best possible realistic approach to obtain basic insights in the cost effectiveness of the defined control strategies. The approach showed a realistic performance when its output for PVMS was compared with field evidence for similar strategy reported in Kenya (Chema, 1975). In this report a 91% reduction in outbreak incidence was observed in three years application of annual mass preventive vaccination which is comparable to the greater than 85% average reduction in outbreak incidence reduction predicted by our model for the same situation.

The cost-benefit analysis showed that an investment in FMD control can be economically viable in Ethiopia. Despite different degrees of uncertainty and associated risks of losses, all of the proposed control strategies showed, on average, a positive NPV and a greater than unity BCR. Prioritizing the control strategies, however, involves not only the indicated economic performance criteria but also criteria such as technical feasibility, epidemiological efficiency, financial feasibility and riskiness.

At the national level, TVS is the most cost effective strategy having the largest median BCR and NPV, and the least uncertainty and risk of loss. It is also epidemiologically more efficient than RVS in which the median year to achieve the target national outbreak incidence level was about 5 years as compared to more than 10 years for the RVS. Another upside of this strategy, especially compared to PMVS, is that most of the farmers within the target areas of intensive vaccination (market oriented farmers and pastoralists) have a strong motivation to implement vaccination (Jemberu et al., 2015a). Given these considerations, TVC can be seen as the best strategy to eliminate the endemicty of FMD nationally. This finding is in line with the targeted control approach advocated by FAO and OIE to progressively reduce the disease incidence in endemic countries until intensive control at national level is manageable (FAO and OIE, 2012).

RVS is the second best strategy in terms of economic efficiency and it is even the best in terms of mean BCR. The distribution in the economic returns from this strategy, however, indicates a high level of uncertainty even with a high risk of facing negative return values. RVS is the control strategy with the most divergent expert opinions about its effectiveness in reducing disease incidence, explaining the large uncertainty in return values. With its relatively low financial outlay requirement, RVS can be an attractive strategy for a more risk taking decision maker or for a decision maker with a lower availability of resources. RVS is epidemiologically seen the least effective to reduce the incidence to manageable level. This is an important weakness if the country want to progress to a next step of disease control like to the disease free status with or without vaccination.

PMVS showed the least economic performance. Moreover, it requires a large sum of initial investment and a huge amount of vaccine resource which could be difficult in the Ethiopian situation. Unlike the other strategies which have positive net returns starting in the first year of control, the payback period for this strategy was about 5 years. These considerations make it the least preferred strategy from a national perspective.

The economic returns of the nationally applied control strategies vary among production systems. TVS was the most cost effective strategy for CLM and RVS for the other two production systems. TVS gave the highest BCR for CLM simply because most of the high risk areas targeted for intensive vaccination with this strategy were not within the CLM system, resulting in less CLM control costs while some benefits from the obtained outbreak reduction in the other systems is expected to occur in this system as well. As such the economic returns from TVS cannot be interpreted for each production system separately. For RVS, the highest BCR was obtained within the pastoral system followed by CLM. This may be related to the difference in the number of cases per outbreak. The higher the number of cases per outbreak (which was the case of pastoral system), the higher the cost effectiveness of control measures triggered by outbreak number like in RVS. The opposite is true for PMVS. PMVS would be relatively more cost effective if the number of outbreaks is large but the number of cases per outbreak is small as in the case of the Market oriented system.

There are limited national level cost-benefit analysis reports on endemic FMD control in the literature for comparison. A review of cost-benefit analysis studies for endemic Southeast Asian countries (Perry et al., 1999) shows mixed results of positive and negative returns to FMD control and/or eradication. The general trend from these studies is that returns to control are more positive for modern production systems and when a serious trade impact is expected. In the traditional production systems, it was seen that control had more benefits in regions where there is a shortage of draft animals. It is often claimed that the return from FMD control from the perspective of production losses, especially in subsistence systems, is low (Perry et al., 2003; Rushton, 2009, 2008) and that the economic analysis for FMD control should be more concerned with its trade effect than production effects (Randolph et al., 2000). This study, however, showed that FMD control could be a profitable investment even in a traditional, largely subsistence, production system without major export considerations.

A cost-benefit analysis of disease control requires a large number of inputs. Identifying the magnitude with which inputs affect the outcome of an analysis through sensitivity analysis gives insights about the robustness of the model outputs. It also helps to identify which input data should be collected with more accuracy to make the model output more robust. In this study, the input parameters to which the BCRs of all control strategies were most sensitive were outbreak incidence reductions due to control strategies, especially in the CLM system. Since there is no large scale experience with applying structural FMD control in Ethiopia, we had to use experience from other countries and generic knowledge. Therefore, the values for these parameters were obtained from expert opinions. A wide difference of opinions among the experts as seen in this study was a concern about the accuracy of these input parameters. However, a breakeven analyses indicated that the breakeven values are far lower than the most likely estimates of all experts but one, which suggests that even in a possible overestimation by experts about these values, the economic profitability of the control strategies are still maintained. The other parameters to which the BCRs show relatively more sensitivity were milk loss per infected cow in the CLM system, and vaccination costs for TVS and PMVS. The milk loss in CLM system constitutes the largest loss item and subsequently the largest benefit from control strategies accrue in the terms avoided milk loss. So it is not surprising the cost-benefit analysis results are sensitive to milk loss. For the current analysis the distribution of milk loss for CLM was used from one time study (Jemberu et al., 2014). More studies may be needed to determine an unbiased value for this important parameter. A cost of vaccination was another important parameter to which economic returns especially from TVS and PMVS were sensitive. Determining an accurate value for this parameter, however, is relatively easy and its impact for the uncertainty of the analysis would be minimal.

Disease control at the national level, like the ones considered in this study, could affect markets of commodities and factors of production in the whole economy. There are various economic analysis techniques within partial and general equilibrium analyses frameworks that can be used for analyzing such market effects (Rushton, 2009). However, no market effects of control strategies in this study were considered due to lack of market structure data which are needed to undertake such complex analysis. In addition to the practical problem of getting market structure data (supply and demand elasticities) for the commodity affected by the control such as live animals and draft power, the authors expect that the price effect of the control would be minimal as it is unlikely that the increase in production would increase market supply. This is primarily due to the fact that main production systems are subsistence oriented and only a little of the increased production will be reflected as increased supply at the market. For example, it is estimated that less than seven percent of the annual milk production in Ethiopia is marketed (Yilma et al., 2011). Another reason, in the case of milk, is that Ethiopia is a net milk importer country, spending tens of millions of dollars for imports of milk products every year (Yilma et al., 2011). As such no price reduction is expected as a result of an increase in domestic milk supply. Besides, the proportion of the increase in the produces relative to the total national annual productions is small. For example, the proportion annual loss of milk, draft power and mortality loss due to FMD to the total annual production are circa 1.2%, 0.65% and 0.23%, respectively and as such the avoided losses due to control may not significantly affect the market supply. But in the long term the improvement of disease situation may lead to a modernization of the husbandry system and a market effect will then be inevitable.

6.6 Conclusions

The average total annual costs of FMD in Ethiopia are estimated at 1, 354 million birr which is equivalent to about 0.14% of the country's GDP. The estimated costs did not account for some invisible and indirect impact of the disease and can as such be considered as a conservative estimate.

The cost-benefit analysis of alternative control strategies varying in intensity of vaccination, showed that an investment in FMD control can be economically effective. However due to uncertainties in several input parameters, the expected economic returns show a large variation, including a risk of loss. The strategy of targeted vaccination, which involves intensive vaccination in high FMD risk areas with ring vaccination and movement restriction during outbreaks in the rest of the country, provides the best economic returns with low risk of loss, and reduces the outbreak incidence rate to the target level within a reasonably short period of time. More studies to generate data, especially on production impact of the disease and effectiveness of control measures are needed to improve the rigor of the analysis, and the framework developed in this paper provides a guide on which data need to be targeted.

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Appendixes

Appendix 6.1. Experts' opinion about impact of different control strategies on outbreak and case incidence reductions (%) per production system

Experts	CLM system						Pastoral system						Market oriented system					
	Outbreak incidence			Case incidence			Outbreak incidence			Case incidence			Outbreak incidence			Case incidence		
	[a]MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX
Ring vaccination strategy																		
1	15	35	50	20	40	50	10	20	45	25	35	60	30	50	80	30	70	75
2	0	5	10	0	5	10	5	10	15	5	10	15	10	15	20	15	20	25
3	0	5	10	5	15	20	0	2	5	0	10	15	0	5	20	5	20	30
4	0	35	70	0	35	70	0	35	70	0	35	70	0	35	70	0	35	70
5	-20	-10	10	-30	-10	10	-30	-10	15	-50	-20	10	-10	0	10	0	20	30
Targeted vaccination strategy																		
1	40	60	80	20	40	80	30	50	70	30	60	75	70	80	90	60	80	90
2	5	15	25	5	15	30	35	50	65	35	50	65	50	65	80	50	60	70
3	30	50	70	20	40	60	20	40	50	20	50	80	30	60	70	30	50	80
4	0	10	20	0	35	70	0	10	20	0	35	70	0	10	20	0	35	70
5	-15	5	30	-15	0	20	-20	5	25	-15	10	25	0	40	65	0	25	45
Preventive mass vaccination strategy																		
1	30	60	75	60	75	90	40	60	70	50	60	75	50	75	90	75	80	90
2	65	75	85	50	60	70	65	75	85	55	65	75	70	80	90	60	75	90
3	40	55	70	20	40	60	20	40	50	20	50	80	30	60	70	30	70	90
4	0	35	70	0	35	70	0	35	70	0	35	70	0	35	70	0	35	70
5	-10	10	30	-10	10	25	-15	5	20	-15	10	20	0	40	60	0	25	40

[a]MIN = minimum; ML = most likely; MAX = maximum

Appendix 6.2. Cost calculations and assumptions for control programs

Whereas the variable costs were directly estimated based on their market price, the fixed costs were accounted in different indirect ways. For example, laboratory facilities, vaccine production facilities and transport facilities were valued in the form of fees (e.g. fee for laboratory sample testing), prices (e.g. import price of vaccines) and rents (e.g. cars). The opportunity cost of veterinary labor was based on the daily rate of the gross salary of a permanent veterinary staff member.

In the following sections, a detailed description is given on the calculations and assumptions made to estimate the costs of outbreak investigations, animal movement restriction enforcements, vaccination application, post vaccination sero-monitoring, regular surveillance activities and staff capacity development.

i. Estimating costs of outbreak investigation

The costs of an outbreak investigation and conformation involve the costs related to the collection and analysis of epidemiological data, the collection of laboratory samples, and the laboratory confirmation process.

Epidemiological data and laboratory sample collection: this task is assumed to involve a team of 3 personnel (an epidemiologist, a technician, and a local community organizer), which is collecting data for 5 days while using one car with which the team drives 1500km on average. In all of the following cost calculations the daily cost of staff personnel involved in the activities is based on the daily rate of their gross salary with the inclusion of a daily field allowance, while labor provided by local community organizer is valued at the level of the daily field allowance. The costs of data and sample collection for an outbreak will therefore be equal to;

Manpower costs = (1 Epidemiologist *450 birr daily cost[11] + 1 Laboratorian Technician* 370 Birr daily cost + 1 local community organizer *150 birr daily field allowance) * 5 days = 4 850 birr

Car rent = 1500 birr/day* 5 days = 7 500birr

Fuel costs = 1 lit fuel/ 5 km * 1500 km * 20 birr\lit =6 000 birr

Total costs for data and sample collection = manpower costs + car rent + fuel costs= 18 350 birr/outbreak

The calculation of the costs related to the laboratory testing (confirmation and serotype identification) are based on the assumption of processing 20 quality samples for

11 Daily cost refers to daily field allowance due to the staff and daily rate of his gross salary.

Chapter 6

outbreak confirmation at a cost of 120 birr/sample to test for a single serotype. The cost of testing 20 samples for 5 relevant serotypes: A, O, SAT 1, SAT 2 and SAT3 (serotype C has never been reported for decades and serotype Asia 1 has never been reported in Africa) subsequently equals to 20 samples * 120 birr/sample/serotype * 5 serotypes = 12 000birr

Total cost of outbreak confirmation = Costs for data and sample collection + costs of laboratory testing = **30 350 birr/outbreak**

ii. Estimating cost of movement restriction enforcement

Currently there is no animal movement regulation in place. The animal disease control proclamation (proclamation number 267/2002) provides a legal framework to enforce animal movement restrictions when an outbreak occurs. Enforcement within this framework is assumed to be focused on the four major livestock routes (for market or other purposes) directing transports out of a district as animal movements will be monitored at these sites during the period of an outbreak. It is also assumed that it will require two persons working in two shifts per site during the day until the outbreak dies out (on average 3 within months) with a monthly payment of 1 500birr to enforce the movement restrictions. Monitoring of the outbreak and final lifting of restrictions when the disease stops is assumed to be done by the regular activity of the veterinary services in the districts. The cost of animal movement enforcement per outbreak according to the above assumptions will therefore be equal to:

2 persons/site * 4 sites *1 500 birr/month* 3months = **36 000birr/outbreak**

iii. Estimating the cost of vaccination

Cost of vaccination was calculated based on the costs of vaccine, vaccine distribution and vaccine delivery, and cold storage.

Cost of vaccine: The vaccine cost is the price of vaccine as paid at the National veterinary institute (NVI). A trivalent vaccine is considered for the central and southern parts of the country (70% of the cattle population) and a bivalent vaccine for the northern part of the country (North of North Shewa which represents 30% cattle population). Monovalent vaccine is considered for ring vaccination. The price of imported vaccine, which was higher than locally produced vaccine of the same type, was used in the cost calculation. This to account for fixed cost of investment needed for vaccine production if all vaccine has to be produced within the country. The price of imported trivalent vaccine quoted by NVI in 2013 was 16 birr. The price of bivalent and monovalent vaccine was then adjusted accordingly as 13 birr and 10 birr respectively. These prices were used as most likely, minus 50% as minimum value and plus 50% as maximum value to parameterize a triangular distribution for price distribution. Some level of vaccine wastage (some estimate up to 10 can be expected for various reasons like missed shooting due to animal reaction, failure of cold chain storage or long stay after reconstituted etc., however these costs are assumed to be compensated by the costs savings resulting from the fact that not all targeted cattle will be accessed and vaccinated.

Cost of vaccine distribution and delivery: It is assumed that the vaccine deployed from NVI is distributed to each district where it is temporary stored and daily taken to vaccination sites within the districts. The vaccination delivery is assumed to be effected by district veterinary personnel (government employee) with an additional payment of field allowance. It is assumed that a vaccination team consists of four people (1 coordinating veterinarian, 2 vaccination technicians and 1 local community coordinator) using a car to drive 200km per day and which will be able to vaccinate 2000 animals per day. So the cost of vaccination will be equal to:

Manpower costs = 1 district veterinarian * 400 birr daily cost+ 2 veterinary technicians*270 birr daily cost + 1 community coordinator*150 birr daily allowance = 1 090birr/day

Car (with driver) rent = 1 500 birr/day

Fuel costs = 1 lit/ 5 km * 200 km * 20 birr /lit = 800birr/day

Total cost per day = 1090+1500+800 =3 390 birr/day

Vaccination cost per animal = 3390birr /2000 animal = 1.7 birr /animal

Other miscellaneous costs like shipping the vaccine form the center to the districts, vaccination organization cost, and cost of other supplies like vaccine syringes, gloves, disinfectants etc. are roughly estimated to be equal to 0.30 birr/ animal

Total vaccine delivery cost per animal = **2 birr/animal**.

Note: this cost assumes good organization in which 2000 animals will be made accessible for the vaccination team in a day and the cost associated with farmers' time in handling their animal for vaccinating is not counted.

Cost of cold storage: To store about 80 000 doses of vaccine in a district, a freezer capacity of at least 500L is needed, reflecting an estimated price of 20 000birr. It is roughly assumed that the useful of freezers equal to the analysis period. For 731 districts nationally

Cold storage for districts = 731*20 000birr = 14 620 000birr

Similar capacity of cold storage is needed at national or regional level for preventive mass vaccination and a third of this capacity for targeted vaccination (as it involves on one third of the vaccinable national cattle population annually) and a sixth of it for Ring vaccination (as it is the expected a sixth of the vaccinable cattle population would vaccinated annually specially in the first few years of the control)

Central and district level cold storage for preventive mass vaccination = 14620000+14620000 = **29 240 000birr**

Central and district level cold storage for targeted vaccination = (14620000birr*0.33) +14620000 = **19 444 600birr**

Central and district level cold storage for ring vaccination = (14620000birr*0.167) +14620000 = **17 061 540 birr**

iv. Estimating cost of sero-monitoring

Within the calculation it is assumed that the sero-monitoring will be done by 15 regional laboratories once every year after vaccination. For this monitoring the laboratories need to sample and test about 400 random samples from the vaccinated cattle population in their mandate areas. The cost subsequently involves serum sample collection and laboratory testing.

Sample collection: To collect 400 serum samples, a team of 3 persons (vet epidemiologist, vet laboratory technician and a local community organizer) is needed for a period of 10 days while using a car to drive on average a distance of 2000km. The cost of serum sample collection will be equal to:

Manpower costs = (1 Vet. epidemiologist * 450birr daily cost + 1 Vet. lab. technician* 370birr daily cost + 1 local community organizer *150 birr daily field allowance)*10 days * 15 regional teams = 145 500 birr/year

Car (with driver) rent = 1500 Birr/day *10 days * 15 regional laboratories = 225000 birr/year

Fuel costs = 1 lit fuel/ 5 km * 2000 km* 20 birr/lit * 15 regional teams = 120 000 birr/year

Sample collection material = 400 samples * 10 birr/sample* 15 regional laboratories = 60 000birr/year

Laboratory testing (liquid phase blocking ELISA: 400samples * (180 birr/sample for three serotype * 0.7 + 120 birr/sample for two serotype*0.3)*15 regional laboratories = 972 000birr/ year

The total cost of sero-monitoring for preventive mass vaccination = 1 522 500 birr/year

The total cost of sero-monitoring for targeted vaccination which involves vaccination of about a third of cattle population that is vaccination in a preventive mass vaccination will be 0.33*1 522 500 = **502 425** birr/year

The total cost of sero-monitoring for ring vaccination will depend on the number of outbreaks. So the calculation is per outbreak instead of per year. The same team of experts as described above will be required to collect the same number of samples but will collection is more concentrated and therefore assumed to require less number of days and distance travelled (5 days and 500km) . Moreover, the samples will be tested for a single serotype. So the cost per outbreak will be:

Manpower costs= (1 Vet epidemiologist * 450birr daily cost+ 1 Vet lab. technician* 370 birr daily cost + 1 local community organizer *150 birr daily field allowance)*5 days = 4 850 birr/outbreak

Car (with driver) rent = 1500 Birr/day *5 days = 7 500 birr/outbreak

Fuel costs = 1 lit/5 km * 500 km * 20 birr/lit = 2 000 birr/outbreak

Sample collection material = 400 samples * 10 birr/sample = 4 000birr/outbreak

Laboratory testing = 400 samples * 60/sample = 24000 birr/outbreak

Total sero-monitoring cost for RVS per outbreak = **42 350 birr/outbreak**

v. Surveillance costs

These include the cost of outbreak detection and reporting, outbreak investigation, and sero-surveillance. The outbreak investigation cost is already estimated as part of the cost of the disease control program as described above. Based on a control plan drafted in 2006 by SPS-LLM (2011) the costs of the remainder activities were estimated to **825 826 birr** per year (in 2013 prices) and as such accounted for in the costs calculations.

vi. Human capacity development cost

For effective implementation of control and monitoring programs a staff capacity development in the form of short term training and experience sharing visits in disease control epidemiology and laboratory diagnostics are considered. A lump sum of **5 million birr** in the first two years of the control programs is assumed to reflect the cost for this capacity development.

Chapter 7

General Discussion

7.1 Introduction

The main motivation for the study presented in this thesis was the increasing interest to launch an official control program against FMD in Ethiopia. Such a control program would have the aim of reducing the impact of the disease on production and increasing export opportunities by improving the zoo-sanitary situation of the country (MoARD, 2006; Thomson, 2014). The study was set with an overall objective of generating information on the epidemiology and economics of FMD in Ethiopia to support decision making in its control. This overall objective was broken down into five specific sub-objectives as described in Chapter 1 and the results from these specific studies are presented in the Chapters 2 - 6 of the thesis. This concluding chapter of the thesis discusses the methodological approaches and data used, synthesizes the results from Chapters 2-6, indicates policy implications, provides an outlook on future research, and finishes with the main conclusions of the study.

7.2 Methodological approaches and data

The overall approach of this study is interdisciplinary, involving methodologies from different scientific fields. Methodologies such as statistical epidemiological modelling (Chapter 2) and mathematical epidemiological modelling (Chapter 5) from the field of epidemiology, health behavior modelling (Chapter 4) from the field of social psychology and cost-benefit analysis (Chapter 6) from the field of economics were used to address the different specific objectives of the study. In this section the different modelling approaches and data issues are discussed for their strengths and weaknesses with respect to their application in this study.

The epidemiological study in Chapter 2 models the risk factors for the incidence of outbreaks of FMD at national level. Consequently, the outbreak unit was used as the sampling unit for data collection. Defining an outbreak is often difficult in traditional extensive farming systems. The world organization for animal health (OIE) defines *outbreak* as occurrence of one or more cases in an epidemiological unit, and *epidemiological unit* as a group of animals with a defined epidemiological relationship that share approximately the same likelihood of exposure to a pathogen (OIE, 2015a). Defining these epidemiological units in traditional extensive systems is, problematic because of the continuous contiguity in the whole livestock population. As a result of this difficulty people use different levels of aggregation as epidemiological unit e.g., village (Cleland et al., 1996; Picado et al., 2011), sub district (Ayebazibwe et al., 2010) and district to describe an outbreak. The inconsistency of this usage was also observed in the animal disease reporting system of Ethiopia, where outbreaks are reported at district level or kebele level. This can cause distorted animal health information. In this study, district was used as epidemiological unit as more outbreak data was available at district level than at kebele level. The use of district as epidemiological unit gave the study a low geographic resolution. This lower resolution level was, however, sufficient for the performed analysis, which was aimed for an epidemiological evaluation at national level.

In the risk factor model, a mixed effects logistic regression model was used, by including a random effect for district to control for the clustering effect that arose due to repeated measures of outbreaks within a district in the different years (Dohoo et al., 2003). The use of districts as a sampling unit also raised a question on the possibility of spatial autocorrelation between districts (nearby districts may tend to have similar disease status). As a formal spatial analysis was not possible due to a lack of spatial data, a variable named 'outbreak in the neighbor district' was included in the model to account for the effect of a prior outbreak in a neighboring district (see table 2.1). While this could control the spatial correlation effect in the adjacent districts (districts sharing borders), it would not capture the whole spatial effect that is related to the distance between districts.

In the study of factors that affect motivation of farmers to implement FMD control measures (Chapter 4), a health behavior theoretical framework (model) was used. Behavioral models are often used in public health intervention studies (Glanz et al., 2008). There is evidence that theory-based behavioral interventions are more effective than those lacking theoretical bases (Glanz and Bishop, 2010). Recently, a number of papers use behavioral models to study the behavior of farmers with regard to animal health (e.g. Bruijnis et al., 2013; Ellis-iversen et al., 2010; Gunn et al., 2008; Jones et al., 2015). In this study, the Health Belief Model (HBM), an individual health behavioral model commonly used in public health, was applied. The core principle of the HBM is that individual health behavior is determined by personal beliefs or perceptions about the disease and its prevention or treatment measures (Champion and Skinner, 2008). As such, this principle can also be applied to asses farmers' behaviors in relation to the health of their animals. Application of this model framework in this study helped to structurally evaluate the effect of farmers' behavioral factors on FMD control.

The HBM contains perception constructs related to the disease and its prevention/ control measures that directly affect health behavior. These perceptions are in turn affected by socio-demographic factors called modifying factors (see section 4.2.1). In operationalizing the model, the measurement of the constructs is a critical task. The scales (group of items) used to measure the constructs should be able to validly and reliably measure the intended constructs (Champion and Skinner, 2008). In this study, the scales used to measure the perception constructs in most cases showed a low internal consistency (lower reliability) and hence the individual items of the scales were directly used as predictors instead of forming latent variable for the constructs. This way the results could only be precisely interpreted at the level of individual items instead of at the level of constructs as specified in the model framework.

The HBM outlines a sequence of causal paths from modifying factors through perception constructs to the intended behavior. Ideally this causal sequence has to be analyzed by multivariate techniques like path analysis or structural equation modelling to analyze the relationships along the path of the causal sequence in the whole model (Tanner-Smith and Brown, 2010). In the present study, the data was not suitable for such an analysis. Rather, the sequential cause relationship was analyzed using two separate consecutive analyses. First, the effect of the perceptions on behavior (intention in the context of this study) was analyzed using a binary logistic regression. Then, the effect of modifying factors on perceptions that were found relevant in the first analyses was analyzed using ordinal logistic regression. This approach, while it was enough to test the hypothesized relationship, made assessing the fitness of the whole model as specified in the theory/framework difficult.

Cost-benefit analysis of alternative disease control strategies as performed in Chapter 6 is demanding from modelling and data perspective. It needs a good underlying epidemiological model that reliably predicts the occurrence of the disease under a variety of control strategies, empirical data on the production parameters and the effect of the disease on these production parameters. This is very challenging especially in the Ethiopian situation, where data is scarce in many respects. Ideally, the epidemiological information of FMD and its control should be generated by a simulation model based on the epidemiologic principles of disease transmission and herd immunity. This type of model enables to carry out what-if scenario analyses (Randolph et al., 2000; Willeberg et al., 2011). Spatially explicit herd based mathematical models are commonly used for simulating hypothetical or real disease outbreak incursion in disease free countries or regions (Bates et al., 2003; Durand and Mahul, 2000; Keeling et al., 2001; Martínez-López et al., 2010). This is because disease control measures in these countries are applied at farm level. Examples of such measures include stamping out infected farms or emergency ring vaccination around outbreak farms. These types of models are not directly relevant to the endemic situation where farm/herd level measures like stamping out are not economically feasible nor epidemiologically essential. Developing a spatial model for the endemic situation in this study was also not feasible because of lack of data (e.g. data on spatial location, farm structure, and animal movement were not available). An attempt was made to develop a mathematical non-spatial individual animal based state transition model (Chapter 5). Because of the assumptions that were needed to be made during the estimation of the model parameters from the limited available data, its predictive performance was found unrealistic (see Chapter 5 for detail discussion the model's performance and its limitations). Moreover, this non-spatial model could not simulate the impact of the control measures as considered in the cost benefit analysis of Chapter 6. Because of these limitations, a simple epidemiological simulation model with straightforward relationships between incidence and control, parametrized by expert elicitation, was used in the cost-benefit analysis. Stochastic simulation and an accompanying sensitivity analysis were employed to mitigate data scarcity and quality problems.

National disease control programs have potential effects on market prices which could affect the valuation of costs and benefits in the cost-benefit analysis. Such market effects could be, for example, increase in market supply of products when the disease burden is reduced. Increase in market supply can be caused by lower production losses in the existing production systems or by the increased use of high yielding, disease susceptible animals because the fear of the disease is minimized. These market effects of disease control can be analyzed using a partial equilibrium framework (e.g. surplus analysis) at the sector level or by computable general equilibrium analysis at the level of national economy (Rich et al., 2005). Required data to conduct these kinds of analyses is currently lacking in Ethiopia, and therefore market effects were not considered in the cost-benefit analysis of this study. However, ignoring the market effects will not be expected to affect the performed analysis significantly, due to the dominantly subsistence nature of the livestock production in Ethiopia.

7.3 Synthesis of results

The study has three distinct but interrelated parts that together address the overall objective of the study: generating information for decision support in the control of FMD in Ethiopia. These parts include the epidemiology of the disease as documented in Chapters 2 and 3; farmers' perceptions about the disease and their motivation about its control as presented in Chapter 4; and the economic impact of the disease and its control as presented in Chapters 3 and 6. In this section, the synthesis of the results from these sub-studies is made to draw conclusions with respect to the overall objective of the study.

7.3.1 The Epidemiology of FMD in Ethiopia

Chapters 2 and 3 present epidemiological information that is essential to assess the economic impact of FMD and to define relevant control strategies for its control. Chapter 2 provides an overview of the epidemiology of FMD in Ethiopia without zooming in to geographic and biological details. Unlike previous studies which are mainly based on sero-prevalence (Bayissa et al., 2011; Megersa et al., 2009; Mekonen et al., 2011; Mohamoud et al., 2011; Rufael et al., 2007) and case outbreaks (Negusssie et al., 2010) on specific localities of the country, this study attempted to uncover the national incidence and patterns of FMD outbreaks with formal representation of the different regions and production systems in the country. Evaluations at country level are important for diseases like FMD which are highly transmissible and whose control requires national coordination. The district level outbreak incidence during a five year period (September 2007 through August 2012) disclosed that, on average, more than a quarter of the districts in the country are affected by FMD outbreaks every year. Outbreaks have been reported from all regional states, indicating that the disease is endemic all over the country. The outbreak incidence, however, has been seen to vary from place to place influenced by different factors such as type of production system, market activity, and wildlife proximity. This differential incidence rate can be a basis for a targeted control of the disease by concentrating efforts in places or production systems where the control could have a high impact in reducing the disease transmission and economic losses. This is a type of information needed for a targeted and gradual decrease of the disease burden in an endemic region as outlined in the progressive control pathway of the global FMD control strategy (FAO and OIE, 2012).

The incidence of outbreaks alone does not tell the whole story of the economic importance of the disease. Knowledge of morbidity and mortality during outbreaks is also important, especially when production impacts are considered. Chapter 3 gives information on the morbidity and mortality rates based on a field outbreak study. The animal level morbidity in a district outbreak was 31% in CLM and 45% in the pastoral systems. Morbidity and mortality estimates by Beyi (2012) in the market oriented system show a smaller morbidity rate within district outbreak (12%). Chapter 2 indicates a higher district level outbreak incidence for market oriented systems as compared to subsistence systems (CLM and pastoral systems). So the incidence of district level outbreaks is higher and morbidity rates within outbreaks lower for the market oriented system, and vice versa for the subsistence systems. These differences in the patterns of outbreak incidence and morbidity within outbreaks influence the cost effectiveness of the different control strategies in the different production systems as discussed in section 7.3.3 below.

During the five year study period, outbreaks were caused by four serotypes of FMD virus: serotypes O, SAT 2, A and SAT 1. Notable changes in the epidemiology of the serotypes during the study period were the increased frequency of serotype SAT 2 which overtook the second rank of serotype A hitherto (Ayelet et al., 2009; Gelaye et al., 2005), and the first diagnosis of serotype SAT 1. These changes suggest for a change in the existing vaccination practice from using a bivalent vaccine with serotypes O and A to at least a trivalent vaccine including serotype SAT 2. It was noted that the distribution of SAT viruses is limited in the central and southern half of the country where roughly 70% of all cattle are found. This means for the remaining cattle population in the north of the country, where only serotypes of O and A are occurring, that vaccination by the bivalent vaccine can remain sufficient. Such a strategy will have two advantages: 1) a reduction in the costs of vaccine that arise from an increased number of serotypes included in the vaccine cocktail, and 2) a reduction in the risk of introducing the SAT virus through inadequately inactivated vaccine into SAT viruses free parts of the country. History has shown that in Europe several outbreaks were caused by inadequately inactivated vaccine during FMD control (Beck and Strohmaier, 1987).

7.3.2 Farmers' perception about FMD and its control

In addition to the technical epidemiological and economic considerations, farmers' motivation to implement control measures is an important element for the success of official livestock disease control programs. Chapter 4 investigated farmers' intentions to implement proposed FMD control measures. The result shows that the intentions varied with the type of control measure and with the type of production system. Whereas there was a high intention to implement vaccination free of charge in all production systems, the intention to implement herd isolation and movement restriction was low in the subsistence systems. If vaccination is intended to be charged, the intention to vaccinate dropped, especially in the CLM system. The epidemiological studies in Chapters 2 and 3 indicated that FMD occurred relatively more frequently in the pastoral and market oriented districts than in the CLM districts. This may partly explain the lower motivation of CLM farmers to apply charged FMD vaccination. Moreover, livestock has a relatively lower contribution to the livelihood of CLM farmers than to the livelihood of pastoral and market oriented farmers (Appendix 4.1). The difference in the motivation also seems to have an economic rationale. The farm level FMD outbreak impact assessment (Chapter 3) showed a higher impact in the pastoral system than in the CLM system. A high farm level impact of FMD and an economic profitability of vaccination control was also documented for the market oriented system (Beyi, 2012).

The different motivation in the application of vaccination control can be used to guide costing of a future national official control program. For the market oriented program, where there is high motivation to control and the benefit from control is demonstrable at farm level (Beyi, 2012), vaccine costs can be covered from farmers. To some extent this applies also to pastoralists. But for the CLM system, where motivation to implement charged vaccination is low, subsiding the vaccine would be necessary to secure sufficient participation of farmers in control programs.

Standard vaccination alone may not be enough to effectively control FMD in livestock systems which are dominated by extensive traditional smallholders and has to be supported by sanitary measures such as animal movement control measures (Knight-Jones et al., 2014a). The low intention of subsistence farmers for animal movement control in Ethiopia is therefore a challenge that has to be addressed in the control of highly contagious livestock diseases like FMD.

Chapter 4 also explored perception factors that influenced farmers' intention to implement FMD control measures. Perceptions of barriers were found to be the strongest predictor of farmers' intentions that negatively influenced the implementation of the control measures. This is consistent with literature in which perceived barriers were indicated to be the most important HBM constructs in influencing health behavior (Carpenter, 2010; Champion and Skinner, 2008; Glanz et al., 2008; Tanner-Smith and Brown, 2010). This information is useful in targeting FMD control promotion towards these barriers.

7.3.3 Economics of FMD and its control

This study is the first in estimating the economic impact of FMD and evaluating the economic feasibilities of potential control options in Ethiopia. The economic impact of FMD was assessed at herd level in Chapter 3 and at national level in Chapter 6. Chapter 3 investigated herd level impacts based on case outbreaks in subsistence systems. The results indicated significant economic impacts for FMD affected households as demonstrated by a loss of up to 7% of the annual household income. Because of the subsistence nature of the farming systems, the losses to affected households are mostly in terms of less food (decreased milk and crop yield) or lower quality food (decreased availability of nutritious animal source foods) indicating a food and nutrition security dimension of the disease's impact.

Chapter 6 assessed the national level economic impact of the disease based on the epidemiological information documented in Chapters 2 and 3, and analyzed the economic returns of potential control strategies defined based on the epidemiological information of Chapter 2 and farmers' control motivation of Chapter 4. The average national economic impact is estimated at about 1.35 billion birr annually which is proportional to 0.14% of the national GDP of 2013. This estimate did not include all possible production and trade impacts of the disease (see Chapter 6 for more discussion in this regard) and as such can be considered as a conservative estimate of the potential losses.

The cost-benefit analyses of three control strategies which are all primarily based on vaccination (reactive ring vaccination (RVS), preventive targeted vaccination (TVS) and preventive mass vaccination (PMVS)) showed, on average, positive economic returns. The salient feature of the cost-benefit analysis outputs was, however, the large variability in output values in which all strategies had the possibility to end up in loss. This variability arose from two stochastic sources in the input data. One source is the natural random variation in some of the input data which is unavoidable like the impact on milk yield of different cows in the same outbreak. The other source of variation is the uncertainty in the input data because of lack of sufficient empirical data. The cost-benefit analyses needed a large number of inputs for which there were limited empirical data available. The model framework developed in this study provides a guide on which data collection needs to be targeted for more robust analyses.

Among the three control strategies, TVS was superior by having the highest benefit cost ratio and the lowest risk of loss. This strategy is also better in other criteria like the initial financial investments needed, the technical feasibility and the epidemiological efficiency. Moreover, most of the farmers within the target areas of intensive vaccination (market oriented farmers and pastoralists) in this strategy had a strong motivation to implement vaccination (Chapter 4). The PMVS which was assumed to involve annual vaccination of the whole national herd was economically the least attractive and the most financially demanding strategy. RVS had a good cost efficiency on average but the weakest side of this strategy was its high riskiness and poor epidemiology efficiency. In conclusion, TVS is the best strategy and it is in line with the progressive control pathway (PCP-FMD) approach for endemic countries as promoted in the global FMD control strategy (FAO and OIE, 2012).

If the control measures would be applied in each system independently, RVS gives better economic returns for subsistence systems and PMVS gives the best economic returns for market oriented system. This may be related to the difference in the pattern of outbreak incidence and morbidity within outbreaks discussed in section 7.3.1. If the frequency of outbreak is lower and morbidity per outbreak is higher, control measures triggered by outbreak frequency like RVS would be relatively more cost effective. In contrast, if the frequency of outbreaks is high but the morbidity within outbreak is small, regular measures like PMVS would be relatively more cost effective.

The major costs estimated in the cost-benefit analyses were those associated with direct production losses. Export impact was considered only partially. The export benefits considered in the analysis was the reduction of FMD sero-positivity in export destined animals and a subsequent reduction in the number of animals rejected from export. Export benefits in terms of accessing new markets or avoiding risk of bans in the existing markets were not considered. The ambitious plan of the government to boost export by control of FMD could not be guaranteed by the control situation defined in this study. According to the current standards for safe international trade in animal and animal products, export to free countries needs reginal/national freedom from the disease (OIE, 2015b), which could be difficult to achieve and maintain. Moreover, freedom is needed not only for FMD, but also for the other major transboundary diseases of ruminants such as contagious bovine pleuropneumonia, lumpy skin disease and peste des petits ruminants which are still endemic in the country. A feasible option in this regard would be to use trading strategies that do not require geographic freedom from disease such as commodity based trade (Scoones et al., 2010; Thomson et al., 2004) which will be feasible once the endemicity of the disease is eliminated.

Despite partial consideration of export benefits, the economic analysis showed that, on average, the return on FMD control is positive. FMD is generally considered as a trade disease. Its direct impact on production in smallholder subsistence systems is considered low and its control is often justified on grounds of expected trade benefits (Perry et al., 2003; Randolph et al., 2000). In relation to this, there is an ongoing debate whether FMD control is beneficial for the poor smallholder livestock keepers who have less connection to international markets (Perry and Rich, 2007; Perry et al., 2003; Scoones and Wolmer, 2007). This study indicates that FMD control can be economically justified based on the reduced production losses in subsistence smallholder system. Moreover, under the current situation in Ethiopia, source of export animal and animal products are smallholder livestock keepers, especially pastoralists. As such they also benefit from FMD control from trade perspective as well. So control of FMD benefits the smallholder livestock keepers in Ethiopia whether from production or trade perspective, however, this study cannot confirm whether control of FMD is the main priority compared to the control of other livestock diseases.

7.4 Policy implications

The risk of a FMD outbreak varies from place to place within the country because of differences in risk factors (chapter 2). This suggests that when resources are scarce, a control policy shall first target high risk areas or sectors where the control could have a high impact by reducing the disease transmission and economic losses.

Since there is a significant impact of FMD outbreak on the livelihood of affected households in the subsistence production systems (Chapter 3) as well as on national economy (Chapter 6), the problem of FMD should be considered by policy makers as both an issue of food and nutrition security, and of national economic development.

Control of FMD nationally is expected to generate positive economic returns by reducing production losses irrespective of any significant improvement in the export situation (Chapter 6). Therefore, FMD control is a viable investment even without the consideration of international trade benefits and can be pursued irrespective of the export situation.

The motivation study in Chapter 4 showed that vaccination is an acceptable method of control. But charging the costs of vaccination reduces the motivation, especially in CLM farmers. This means that the main tool for control of FMD in Ethiopia should be vaccination with the consideration of subsidy for the vaccine costs. For highly contagious diseases like FMD, however, it will be necessary to include some degree of animal movement restriction. Given the high perceived difficulty and low intention of subsistence farmers to implement animal movement restriction, a strong extension work is needed to implement movement restriction at least during an outbreak.

Throughout this study, differences between the different production systems have been identified like in terms of the epidemiology of the disease (Chapter 2), the motivation of farmers to implement control measures (Chapter 4), and the economic impact and benefits of its control (Chapters 3 and 6). One of the key messages for policy makers is, therefore, the need to account for these differences between production systems when tackling the FMD problem in Ethiopia.

7.5 Future research outlook

This thesis provides relevant insights to support decision making in the control of FMD in Ethiopia. There are, however, additional areas of research in the epidemiology and economics of the disease that needs to be done to improve the decision support process in the disease's control.

The present study indicated a high risk of FMD in districts with or adjacent to national parks and wildlife sanctuaries. However, the maintenance of FMD virus in wildlife, except SAT viruses in wild buffalo, has never been confirmed (Bastos et al., 2000; Thomson et al., 2003). Given the small population of buffalos in Ethiopia, the importance of wildlife in FMD transmission and maintenance could be doubtful and needs further study.

One of the challenges in modeling the economic effects of the control strategies was the lack of information about the field effectiveness of FMD vaccination. Field effectiveness evaluation of livestock vaccination is important in guiding control policy (Knight-Jones et al., 2014b). Such a field effectiveness evaluation of FMD vaccination in Ethiopia is an important research area to have a solid foundation for an economic impact analysis of FMD control.

For epidemiological and economic impact evaluation of FMD control, mathematical simulation models are essential tools (Willeberg et al., 2011). In this study developing such a model was not successful due to the limited availability of data (chapter 5). Collecting more data that enable the development of a spatial mathematical model that can simulate the disease outbreak dynamics under different control strategies is necessary to provide more flexible decision support information in the control of the disease.

The effect of FMD control on export improvement was not fully studied in this research. Decreasing the outbreak incidence obviously decreases the risk of exporting infected animals or animal products, and will minimize the chance of an export ban arising from such incidents as the Egypt ban of Ethiopian live animal and meat in 2006 (MoARD, 2006). These types of positive effects of FMD control were not captured in this study. Studying all potential benefits of trade will be necessary to appreciate the full benefits from the disease control. When a sanitary investment needs to be made to improve export trade, another aspect that should be taken into account is the export capacity of the country. Different control options with different export capacity scenarios need to be studied.

National level disease control programs have a potential to affect the market prices. These effects were not taken into account in the cost benefit analysis undertaken in this study. Incorporating the market effects in the analysis would give more reliable estimates of benefits of the control, and its welfare distributional impact across the different groups in the society.

The use of a behavioral theory, the HBM, in studying the motivation of farmers to implement official control measures has been a new approach in the veterinary disease control. The HBM framework was employed to structure the behavioral factors affecting the motivation of farmers towards FMD control; however, the constructs of the model were not strictly measured and applied. Proper application of the model requires the development of standard instruments (scales) for measuring the model constructs. Scales that take into account the husbandry system, the nature of the disease and the epidemiological situation should be developed. The scales should be checked for content and construct validity before use (Champion and Skinner, 2008). Such scales developed for one disease situation can be easily adapted for other situations by including and excluding some component items or question from the scales.

7.6 Conclusions

Based on the main results of the research presented in this thesis, the following conclusions are drawn:

- Foot and mouth disease is endemic in all parts (regional states) of Ethiopia with variable outbreak incidences in different geographic zones of the country. The highest incidence was in the central and south eastern parts of the country. Districts with a market oriented production system, livestock markets or trade routes, or adjacent to national parks or wildlife sanctuaries are at a relatively high risk of an FMD outbreak. Livestock population in these high risk areas can be considered as the first targets of control (Chapter 2).

- FMD virus serotypes O, SAT 2, A, and SAT 1, in order of decreasing frequency, were the cause of outbreaks during the study period (2007 to 2012). Serotype SAT2 is increasing in relative frequency of occurrence. The distribution of serotypes O and A are country wide, but the SAT serotypes occur in the central and southern half of the country, which suggests a need for different vaccine valencey for the different regions of the country (Chapter 2).
- Farmers in all production systems are motivated to implement free FMD vaccination but are less motivated to implement herd isolation and animal movement restriction as control measure. If costs of vaccination are charged, the motivation of vaccination decreases, especially in the crop-livestock mixed system. Vaccination, with consideration of subsidy can therefore be considered as the main acceptable tool of FMD control in Ethiopia (Chapter 4).
- Perception of barriers to implement control measures, such as costs of vaccination, and difficulty of herd isolation and animal movement control are the most important factors that affect farmers' motivation to implement control measures. These barriers need to be addressed by extension and promotion activities for a successful implementation of an FMD control program (Chapter 4).
- The economic impact of FMD, both at herd and national level, is large with food and nutrition security implication that warrants a national control consideration (Chapters 3 and 6).
- The economic returns of national control strategies, which are designed to eliminate endemicity of FMD in Ethiopia are, on average, positive. However, the estimates of the economic returns showed large stochasticity, and hence more epidemiological and economic input data is needed for more robust outputs (Chapter 6).
- Targeted vaccination strategy is economically and epidemiologically the most efficient and financially the least risky strategy, and hence the strategy of choice to eliminate the endemicity of FMD in Ethiopia (Chapter 6).

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Summary

Foot and mouth disease (FMD) is one of the endemic transboundary diseases that have significant socio-economic importance in Ethiopia. The disease impacts production and trade in animal and animal products. The growing trend of private investments in the livestock sector and the increase in export of live animals and meat in recent years, coupled with the growing international concern on the zoo-sanitary importance of the disease have aroused interest to launch an official FMD control in Ethiopia. Sufficient epidemiological and economic information at national level that is needed to support the decision making on how to control the disease is, however, lacking. The overall objective of this research was, therefore, to study at national level the epidemiology and economics of FMD and its control in Ethiopia.

The national epidemiology of FMD in Ethiopia was studied in Chapter 2, based on a five year (2007/8 through 2011/12) outbreak occurrence data collected from a representative random sample of districts in the country. The national incidence of FMD outbreaks was determined, and FMD specific risk factors along with its geographic and temporal trends were identified. The frequency and distribution of viral serotypes were also studied based on secondary data collected from institutions that conduct outbreak investigations in the county. The national incidence of FMD outbreaks during the indicated study period was 1.45 outbreaks per five district years. Mapping of the outbreaks indicated that the disease was geographically widespread affecting all major regional states in the country and more frequent in the central, southern and southeastern parts of the country. Time series analysis of outbreak incidences did not reveal any long term or seasonal trends. A mixed effect generalized linear modeling of several putative risk factors indicated that the type of production system (market oriented system versus subsistence systems), presence of a major livestock market and /or route, and adjacency to a national park or wildlife sanctuary were associated with an increased risk of an outbreak in a district. FMD virus serotypes O, SAT 2, A, and SAT 1, in order of decreasing frequency, were identified as the causal serotypes of the outbreaks during the period covered by study. Whereas serotype O and A were widely distributed in the country, SAT viruses were limited in the central and southern half of the country. This differential information on the risks of the disease and types of virus is of relevance in defining a targeted progressive FMD control policy.

In Chapter 3, the clinical and direct economic impacts of FMD at household herd level in smallholder livestock farming systems were investigated. Impacts were assessed based on data obtained from case outbreaks in cattle in the crop-livestock and pastoral production systems that occurred in 2012 and 2013. FMD morbidity rates of 85.2% and 94.9% at herd level and of 74.3% and 60.8% at animal level in the affected herds were determined for crop-livestock mixed system and pastoral system, respectively. The overall and calf specific mortality rates were 2.4% and 9.7% for the crop-livestock mixed system, and 0.7% and 2.6% for the pastoral system, respectively. The resulting economic losses of FMD due to milk loss, draft power loss and mortality were on average USD 76 per affected herd and USD 10 per head of cattle in the affected herds of the crop-livestock mixed system, and USD 174 per affected herd and USD 5 per head of cattle in the affected herds of the pastoral system. The major loss due to the disease occurred as a result of milk losses and draft power losses, whereas mortality losses were relatively low. The losses in the affected herds represent a significant portion of the annual income of the smallholder farmers.

In Chapter 4, the intentions (motivations) of farmers in implementing FMD control measures in Ethiopia and their perceptions about the disease and its control measures that influence these intentions were explored using the Health Belief Model (HBM) framework. Almost all farmers (99%) had the intention to implement FMD vaccination free of charge. Whereas the majority of farmers in the pastoral (94%) and market oriented (92%) systems also had the intention to implement vaccination with charge, only 42% of the crop-livestock mixed farmers had the intention to do so. The majority of farmers in the crop-livestock mixed (82%) and pastoral (98%) systems had no intention to implement herd isolation and animal movement restriction. Among the HBM perception constructs, perceived barrier was found as a significant predictor of the intention of farmers to implement the charged vaccination control measure. Perceived susceptibility, perceived benefit and perceived barrier were the significant predictors of the intention for herd isolation and animal movement restriction measure. The type of production system and age of farmers were the husbandry and socio-demographic factors with a significant influence on the relevant perceptions of the intention to implement the FMD control measures. FMD control promotion programs aimed at increasing farmers' motivation to implement vaccination with charge and herd isolation and animal movement restrictions during an outbreak should give more attention to the perceived barriers and account for the differences in perceptions among the production systems.

In Chapter 5, the possibility of developing and parameterizing a simple FMD transmission mathematical model for typical districts representative of the crop-livestock mixed and pastoral livestock farming systems of Ethiopia was explored. The model was particularly aimed to predict the magnitude (morbidity and mortality cases), and durations of FMD outbreaks, and to use these outputs of the model for further economic analysis of FMD and its control. A stochastic SIR model was formulated and parameterised with data obtained from literature as well as from field data. The key model parameters such as the basic reproductive ratio (which was used to derive the transmission rate parameter) and rate of loss of immunity were estimated form cross-sectional sero-prevalence data by means of a maximum likelihood estimation.

Simulation of the SIR model using the estimated parameters resulted in a prediction of outbreak characteristics that were unrealistic when compared with field outbreak data. The chapter subsequently concludes with a critical reflection on the unavoidable assumptions underlying the model and the poor quality of data, while highlighting areas for improved modelling in the future.

Chapter 6 describes the assessment of the national economic impact of FMD in cattle production systems of Ethiopia as well as the *ex ante* cost-benefit analyses of potential control alternatives. The annual costs of FMD were assessed based on production losses, export loss and control costs. The total annual costs of FMD under the current status quo of no official control were estimated at 1,354 (90% CR: 864-2,042) million birr. The major cost (94%) was due to production losses. The cost-benefit of three potential control strategies: 1) ring vaccination (reactive vaccination around outbreak area supported by animal movement restrictions, 2) targeted vaccination (annual preventive vaccination in high risk areas plus ring vaccination in the rest of the country), and 3) preventive mass vaccination (annual preventive vaccination of the whole national cattle population) were compared with the base line scenario of no official control. Experts were elicited to estimate the influence of each of the control strategies on outbreak incidence and number of cases per outbreak. Based on these estimates, the occurrence of the disease over a period of 10 years was simulated by a stochastic model. Preventive mass vaccination strategy was epidemiologically the most efficient control strategy by reducing the national outbreak incidence below 5% with a median time interval of 3 years followed by target vaccination strategy with a corresponding median time interval of 5 years. On average, all evaluated control strategies resulted in positive net present values. The ranges in net present values were, however, very wide, including negative values. The targeted vaccination strategy was the most economical strategy with a median benefit cost ratio of 4.29 (90%CR: 0.29-9.63). It was also the least risky strategy with 11% chance of a benefit cost ratio of less than one. In general this particular study indicated that FMD has a high economic impact in Ethiopia and that its control is predicted to be profitable. The strategy of targeted vaccination is shown to be the best control strategy because of its largest economic return and relatively lowest risk of losses.

Based on the main findings of the thesis described above, the following conclusions are drawn:

- Foot and mouth disease is endemic in all parts (regional states) of Ethiopia with variable outbreak incidences in different geographic zones of the country. The highest incidence was in the central and south eastern parts of the country. Districts with a market oriented production system, livestock markets or trade routes, or adjacent to national parks or wildlife sanctuaries are at a relatively high risk of an

FMD outbreak. Livestock population in these high risk areas can be considered as the first targets of control (Chapter 2).

- FMD virus serotypes O, SAT 2, A, and SAT 1, in order of decreasing frequency, were the cause of outbreaks during the study period (2007 to 2012). Serotype SAT2 is increasing in relative frequency of occurrence. The distribution of serotypes O and A are country wide, but the SAT serotypes occur in the central and southern half of the country, which suggests a need for different vaccine valencey for the different regions of the country (Chapter 2).
- Farmers in all production systems are motivated to implement free FMD vaccination but are less motivated to implement herd isolation and animal movement restriction as control measure. If costs of vaccination are charged, the motivation of vaccination decreases, especially in the crop-livestock mixed system. Vaccination, with consideration of subsidy can therefore be considered as the main acceptable tool of FMD control in Ethiopia (Chapter 4).
- Perception of barriers to implement control measures, such as costs of vaccination, and difficulty of herd isolation and animal movement control are the most important factors that affect farmers' motivation to implement control measures. These barriers need to be addressed by extension and promotion activities for a successful implementation of an FMD control program (Chapter 4).
- The economic impact of FMD, both at herd and national level, is large with food and nutrition security implication that warrants a national control consideration (Chapters 3 and 6).
- The economic returns of national control strategies, which are designed to eliminate endemicity of FMD in Ethiopia are, on average, positive. However, the estimates of the economic returns showed large stochasticity, and hence more epidemiological and economic input data is needed for more robust outputs (Chapter 6).
- Targeted vaccination strategy is economically and epidemiologically the most efficient and financially the least risky strategy, and hence the strategy of choice to eliminate the endemicity of FMD in Ethiopia (Chapter 6).

About The Author

Wudu Temesgen Jemberu was born on March 31, 1977 in Debre Yakob, Gojjam, Ethiopia. He completed his primary and secondary education in Mertule Mariam, Gojjam. In1994, he joined the Faculty of Veterinary Medicine, Addis Ababa University to study veterinary medicine and graduated with Doctor of Veterinary Medicine in 1999. From 2000-2002 he worked as district veterinary officer under the Bureau of Agriculture of Amhara National Regional State, Ethiopia. From 2003-2004 he did his master's degree in Veterinary Epidemiology at Addis Ababa University. In 2005 he worked as research officer in the Veterinary Epidemiology and Economics department of Kombolcha Regional Veterinary Laboratory, Kombolcha, Ethiopia. In 2006 he joined Faculty of Veterinary Medicine, University of Gondar as assistant professor of Veterinary Epidemiology. In this Faculty he served as head of the Department of Clinical Medicine and Epidemiology form 2007-2008, as assistant dean of the Faculty in 2009, and as dean of the Faculty form 2010 to 2011. Since he joined the Faculty, he taught various courses and published several papers in local and international journals with his colleagues and students. At the end of 2011, he joined Wageningen University to study his PhD in animal health economics at the Business Economics chair group of Wageningen University School of Social Sciences. From 2012 to 2016 he did his PhD research on 'Bioeconomic modelling of foot and mouth disease and its control in Ethiopia'. During his PhD tenure he worked in Royal Veterinary College, University London as visiting researcher for two months. His experience is mainly in the epidemiological and economic modelling of livestock diseases and their control. His research interest is within the wider area of the impact of livestock production and health on society, environment and animal welfare. After his PhD graduation he will rejoin the University of Gondar and can be contacted at:

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Wudu T. Jemberu
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the activity	*Department/ Institute*	*Year*	*ECTS*
A) Project related competences			
Applied economic modelling for the veterinary sciences	GSLS,UU	2012	3
Mathematical modelling of infectious diseases	GSLS, UU	2012	3
Management of infections and diseases in animal populations (QVE 30806)	WUR	2012	-
Advanced agricultural business economics (BEC 30306)	WUR	2012	6
Organization of the agribusiness (BEC 31306)	WUR	2013	6
Macroeconomics and international trade (DEC 21860)	WUR	2012	6
B) General research related competences			
Introduction to WASS	WASS	2012	1
PhD research proposal	WASS	2012	4
Techniques for writing and presenting scientific paper	WGS	2013	1.2
Scientific publishing	WGS	2012	0.3
Quantitative data analysis: multivariate analysis (YRM 60306)	WUR	2013	6
Generalized linear Models	PE&RC	2012	0.6
C) Career related competences/ Personal development			
Project and time management	WGS		1.5
Voice matters	WGS		0.3
PhD seminar (presenting the PhD proposal and paper, and attending biweekly PhD seminars of BEC group)	WUR	2012-15	2
'Incidence of Rabies in North Gondar, Ethiopia'	ISVEE Conference, Maastricht, The Netherlands	2012	1
'Epidemiology of FMD in Ethiopia'	SVEPM Conference, Ghent, Belgium	2015	1
'Incidence and risk factor of FMD in Ethiopia'	GFRA Conference, Hanoi, Vietnam	2015	1
'Economics of FMD and its control in Ethiopia'	ISVEE Conference, Merida, Mexico	2015	1
Total			***44.9***

*One credit according to ECTS is on average equivalent to 28 hours of study load

Colophon

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