Costs and benefits of foot and mouth disease vaccination practices in commercial dairy farms in Central Ethiopia

MSc thesis

Student: Ashenafi, Beyi

Reg.nr: 820518-065-120

Course code: BEC-80430

Supervisor: Henk Hogeveen (Assoc. Prof.)

Business Economics Group

November, 2012

Acknowledgements

First and foremost I would like to thank God for His mercy throughout my study in Wageningen. My gratitude goes next to my supervisor Dr Hogeveen Henk for politeness and hardworking that I learned from him. I would also like to thank people who gave me expertise opinions, dairy farmers in Bishoftu and all people who helped me during the field work in Ethiopia. The Netherland fellowship Programme (NFP) that sponsored my MSc study in Wageningen University deserves great acknowledgement.

Table of Contents

Abstract

Foot and mouth disease (FMD) is endemic in Ethiopia. The economic impact of FMD to the dairy sector is substantially high due to subsequent milk loss, mortality and premature culling. The objectives of this study were to estimate the financial losses of an outbreak and to predict costs and benefits of different vaccination practices in commercial dairy farms in central Ethiopia. A stochastic Monte Carlo cost-benefit simulation model was developed at farm level. The costs and benefits of three scenarios: no vaccination, reactive vaccination and preventive vaccination with an imported quadrivalent vaccine and two sub-scenarios under each main Scenario: treatment and no treatment during outbreak were modelled. The input data were gathered through a field survey at Bishoftu/Debre Zeit, central Ethiopia, expert opinion and literature. During the survey, face to face interviews were carried out with 31 farmers about FMD occurrence and the vaccination status of their farms in the last five years. Six international and four national FMD experts gave their opinions about the likelihood of morbidity and mortality under different scenarios. Out of 31 visited farms, 23 of them had an FMD outbreak at least once in the last five years. The estimated short-term farm level direct financial loss due to outbreak was 45,131ETB (€1,962, 1€=23ETB). The financial losses between the non-vaccinated farms and those undergone reactive and preventive vaccinations prior to the outbreak were not significantly different for all considered variables. The simulation output presented that treatment of sick animals during an outbreak is cost effective for all scenarios. Biannual preventive vaccination with a quadrivalent vaccine has predicted annual net benefits of 21,117ETB (€918) without treatment and 22,446ETB (€976) with treatment over no vaccination/no treatment scenario and the benefit-cost ratio of 5 and 8, respectively.

The overall short-term farm level direct losses associated with previous outbreaks in Bishoftu within a short period of time indicates that the control of FMD is paramount important in the dairy sector in Ethiopia. During outbreaks, neither reactive nor preventive vaccination was helpful in preventing clinical disease, and this finding calls for investigation of why the previous vaccinations failed to do so. The economic damage of an outbreak is lower if there is biannual vaccination and the loss further decreases if it is combined with treatment when there is an outbreak. Therefore, preventive biannual vaccination with a quadrivalent vaccine coupled with treatment whenever there is an outbreak is cost effective in the dairy sector provided that the vaccine strains match with the field strains in central Ethiopia and the vaccine is correctly administered.

Key words: benefit, Central Ethiopia, commercial dairy farms, economic loss, foot and mouth disease, Monte Carlo simulation model, vaccination.

1. Introduction

Foot and mouth disease (FMD) is a highly infectious and economically devastating disease of cloven-footed animals (Bronsvoort *et al*., 2004; Forman *et al*., 2009). It is characterized by fever and vesicular eruptions in the mouth, on the feet and teats. FMD is associated with an aphthovirus (family Picornaviridae) which occurs as seven immunologically distinct major serotypes: A, O, C, Southern African Territories (SAT) 1, SAT 2, SAT 3 and Asia 1 (Radostits *et al*., 2006). FMD is on the A list of infectious diseases of animals of the Office International des Epizooties (OIE) and it has been recognized as a major constraint for international trade of livestock and livestock products (Davies, 2002; Leforban, 2005b).

FMD is a global infectious disease that through the years has affected most countries in the world. Developed countries have eliminated it by killing of infected animals. However, it is endemic in most of the developing countries, which due to several reasons could not eradicate the disease. Lack of eradication of FMD from developing countries poses great threat to livestock industry in developed countries. A striking example is the outbreak of 2001, which occurred due to serotype O Asian type and resulted in severe economic losses in West Europe. In endemic countries, the economic impact of FMD is enormous because it causes production losses and restriction from international market. The production losses emanate from reduced milk yields, abortions, perinatal mortality, lameness, loss of weight in growing animals and premature cull as a result of permanent foot or udder damage (James and Rushton, 2002). FMD can be controlled by mass vaccination with high quality vaccine and restriction of animal movement in endemic areas (Kivaria, 2003).

FMD is an endemic viral disease in Ethiopia. The records of the ministry of agriculture and rural development (MOARD) from 1997 to 2006 show that FMD outbreak occurred everywhere throughout the country with highest incidence in the central part (Ayelet *et al*., 2008). The sero-prevalence of FMD among Borana pastoral cattle in 2008 was reported to be 24.6% (Mekonen *et al*., 2011). Another study that covered broader areas of the country showed sero-positivity of 44.2% with 1.6% and 8.9% mortality and case fatality rates (Negussie *et al*., 2011). Serotype O, A, C, SAT1 and SAT2 were identified from FMD samples collected throughout the country (Ayelet *et al*., 2009). Serotypes O and A are more prevalent and are the major causes of economic losses (Sahle and Rufael, unpublished). FMD impedes export of livestock and livestock products and causes production losses. During the Egyptian trade ban of 2005/2006, Ethiopia lost more than US$14 million (Leforban, 2005a).

Ethiopia has the largest number of livestock in Africa; despite this, the consumption of milk per capital is amongst the lowest in the continent. Nowadays, commercial dairy farms are increasing in number as the demand for milk and milk products is rising in the country. Dairying is a growing industry in Ethiopia and most of the commercial farms are situated in and around the capital and other big cities. Exotic breed or cross breed cows are predominantly kept for their higher production in these farms. Meanwhile, the susceptibility of these animals to FMD and subsequent production losses are higher than the indigenous breeds (Roeder *et al*., 1994). Dairy farms experience great losses during an outbreak of FMD due to the subsequent milk reduction, death and premature culling of highly valuable animals. A study conducted on the Andassa dairy farm, Northwest Ethiopia, showed that the milk yield was reduced by half during FMD outbreak (Mazengia *et al*., 2010).

In Ethiopia, currently there is no country-wide vaccination programme aimed to control FMD. Only a prophylactive vaccination is practised by some dairy herds containing exotic animals (Ayelet *et al*., 2009) and a ring vaccination is carried out around an infected area. Considering the wide prevalence of serotypes O and A, the National Veterinary Institute (NVI) is producing an inactivated vaccine. However, this strategy has not given substantial impact due to limitations in producing sufficient doses and prevalence of other serotypes that are not included in the vaccine formulation. The Ethiopian government has envisaged importing millions of polyvalent FMD vaccines with the intention of maintaining and enhancing export of livestock and livestock products in short term and establishing FMD free export zones in long term. On the other side, the economic return from the FMD vaccination at a farm and a dairy subsector level is not known. Theoretically, if the economic returns of instituting a given disease control strategy is not cost effective, as commercial dairy farms are tailored toward earning a profit, it will be sought for an alternative strategy with a better economic return (McInerney *et al*., 1992). In agro-pastoral production system of Southern Sudan, for instance, the benefit-cost ratio of FMD vaccination was estimated to be 11.5 (Barasa *et al*., 2008) and so control is cost effective. In general, knowing the benefit of a given disease control programme is important in that the policy makers would pass informed decision and farmers would be motivated to participate in the programme.

Objective

The objectives of this study were to estimate the economic losses of an outbreak and to predict the costs and benefits of vaccination under three scenarios: no vaccination, reactive vaccination and preventive vaccination and two sub-scenarios: treatment and no treatment during an outbreak.

1. Literature review

2.1 General overview of FMD

Foot and mouth disease is a highly infectious and economically devastating disease of ruminants and pigs and is one of the most economically important diseases of livestock (Bronsvoort *et al*., 2004; Forman *et al*., 2009). It is characterized by fever, lameness and vesicular eruptions in the mouth, on the feet and teats. FMD is caused by aphthovirus (family Picornaviridae), which occurs as seven major serotypes: A, O, C, Southern African Territories (SAT) 1, SAT 2, SAT 3 and Asia 1. There is no cross immunity among different serotypes and, therefore, immunity against one serotype does not confer protection against other serotypes. The incubation period of FMD virus infection is 2 to 14 days (Grubman and Baxt, 2004; Radostits *et al*., 2006; Parida, 2009).

The severity of an FMD outbreak depends on the strain of the virus and the type of animals. High producing animals are more severely affected both in terms of immediate effect on production and long term damage leading to premature culling (James and Rushton, 2002). The morbidity goes upto 100% in susceptible animals, particularly among exotic high yielding cattle. Drop of milk production in infected milking cows is the cardinal sign of an FMD outbreak in a herd. Mortality is up to 2% in adult cattle and 20% in calves (Radostits et al., 2006; Radostits and Hinchcliff, 2006). The immediate effect of an FMD outbreak also includes abortion of pregnant cows, which is due to high fever, though the virus does not cross the placenta. Permanent foot, udder and thyroid damage cause premature culling (James and Rushton, 2002). Moreover, FMD is on the A list of infectious diseases of animals of the Office International des Epizooties (OIE) and it has been recognized as a major constraint for international trade of livestock and livestock products (Davies, 2002; Leforban, 2005b). Illustrations of its impacts on international trade were the export losses to Ethiopia of US$14 million in 2005/2006 (Leforban, 2005a) and to Zimbabwe of US$ 30millions in 1989 (Thomson, 1995) following FMD outbreaks. Table 1 summarizes morbidity, mortality, abortion rate, premature culling rate, milk loss, duration of milk loss due to FMD outbreak in developing countries.

Table 1: Summary of morbidity, mortality, abortion rate, premature culling rate, milk loss, duration of milk loss due to FMD outbreak in developing countries

Variables	Percentage (%)	Country	Sources
Overall morbidity	35.5	Bangladesh	Chowdhury, 1993
	52.13	Pakistan	Ahmad et al., 2002
	53.2	Punjab, Pakistan	Gorsi et al., 2011
	100	Egypt	Abed El-Rahman et al., 2006
	91	Kenya	Kimani et al., 2005
Morbidity in adult	32.23	Lahore, Pakistan	Khan et al., 2006
Morbidity in young	16.11	Lahore, Pakistan	Khan et al., 2006
	56.47	Punjab, Pakistan	Gorsi *et al*., 2013
Overall mortality	15.25	Punjab, Pakistan	Gorsi *et al*., 2013
	8.2	Kenya	Kimani et al., 2005
Mortality in adult	9.09	Lahore, Pakistan	Khan et al., 2006
Mortality in young	6.19	Lahore, Pakistan	Khan et al., 2006
	22.9	Punjab, Pakistan	Gorsi *et al*., 2012
	50.9	Bangladesh	Chowdhury, 1993
	80	Egypt	Abed El-Rahman *et al*., 2006
Abortion rate	0.65	Lahore, Pakistan	Khan *et al*., 2006
	>3.13	Kashmir	Shah et al., 2011
	0.9	Punjab, Pakistan	Gorsi *et al*., 2011
Premature cull rate	2.42	Kenya	Mulei et al., 2001
	50-60	India	Mathew and Menon, 2008
	51	Ethiopia	Mazengia *et al*., 2010
	66.6	Bangladesh	Chowdhury, 1993
Duration of the outbreak or milk loss (days)	22.7	Bangladesh	Chowdhury *et al*., 1993
	17.88	Pakistan	Kasimi and Shah, 1980

2.2 Global situation and economic impacts of FMD

FMD is a global infectious disease that through the years has affected most countries in the world. FMD has been eradicated from most of the developed countries by a stamping out policy. However, costly outbreaks occur in FMD-free countries (Parida, 2009). Striking example are the recent outbreaks in UK and The Netherlands in 2001. Thompson *et al*. (2002) estimated losses from FMD in the UK at £5.8 to £6.3 billion (US$ 10.7 to $11.7 billion). Generally, in FMD free countries, economic costs emanate from active surveillance during peace time and eradication costs during epidemics. FMD is endemic in much of Africa, Asia and South America (Davies, 2002). In endemic countries, FMD causes huge production losses, precludes access to regional and international markets (Parida, 2009). However, in developing countries, there is little or no information on the micro-economic aspects of FMD (Forman *et al*., 2009).

The economic impact of FMD can generally be categorized into direct and indirect losses. Direct losses are associated with the presence of disease and are either visible or invisible to the farmer. The visible losses are associated with mortality and morbidity losses, which include condemnation, poor weight gains, reduced milk production, poor feed conversion, poor reproductive capacity and poor draught power and additional costs to avoid or reduce disease incidence or to treat infected cattle. Invisible losses, on the other hand, result from unrealized production potentials. Indirect losses are associated with risks of a disease and include losses that limit the exploitation of the available resources as a result of restricted grazing in infested areas, reduced crop production due to exclusion or limitation of draught power, reduction or elimination of trade. In Kenya, direct losses caused by an FMD outbreak due to SAT 1 were estimated at US$ 468,354.4 for four large scale dairy farms. In this outbreak, mortality, premature culling and milk reduction accounted the major causes of direct losses (Kimani *et al*., 2005). In Turkey, the average FMD induced financial losses per milking cow was estimated to US$ 294 (Şentürk and Yalçin, 2008). In Sudan, economic costs of FMD outbreak, which included 50% milk loss for two weeks, death of affected cattle and costs of veterinary drugs, were reported to be US$ 1,771,924 for Khartoum state (El-Hussein and Daboura, 2012).

2.3 Control of FMD

The type of the control strategies applied in a country depends on the goal of the control programme. The control strategies vary from country to country based on their epidemiologic conditions, importance of livestock sector in the national economy and economic capability of the country to invest in expensive control strategies. When an outbreak happens, the control programme in FMD free countries is eradication oriented while in endemic countries is to curb the economic losses. In disease free countries, during epidemics, animal movement is restricted, infected farms are quarantined and infected and in-contact susceptible animals are slaughtered. With the intention of containing the spread of the disease, susceptible farms within 1-2 km of distance are vaccinated and then slaughtered when the outbreak is controlled (Sutmoller et al., 2003; Grubman and Baxt, 2004). During peace time, there is often an on-going active surveillance activity (James and Rushton, 2002). In endemic countries, the targets of control programme are to reduce production losses in short term and, in some cases, to eradicate the disease in long term. During the phase of an outbreak, infected farms are quarantined and animal movement is restricted. Also, ring vaccination is done around the infected area to break the spread of the outbreak. In peace time, massive vaccination, restriction of animal movement to disease-free areas and surveillance are carried out (Kivaria, 2003).

Vaccination is instrumental in the control of FMD in endemic countries. FMD vaccines commonly contain more than one serotype of virus depending on the epidemiological condition of the particular country. The current FMD vaccine confers protection for six months and hence at least two vaccinations are recommended for prophylactive protection in an endemic area. In vaccinated cattle, peak antibody response is attained in 21 to 28 days and protection can be achieved within one to two weeks post vaccination (Doel, 1996; Davies, 2002; Parida, 2009). Vaccination with good quality FMD vaccines can help to prevent losses in livestock production and reduce the overall incidence of the disease in sub-Saharan Africa as eradication of FMD by the implementation of slaughtering-out is impractical for several reasons (Pamela, 1998).

2.4 FMD situation in Ethiopia

In Ethiopia FMD is an endemic disease. Except SAT3 and Asia 1, the other five serotypes were isolated from FMD samples collected between 1981 and 2007 throughout the country from cattle and pigs (Ayelet *et al*., 2009). Serotype O is the most dominant and prevalent serotype followed by serotype A. Identification of serotypes using Complement Fixation test (CFT) carried out on 215 cell culture positive samples collected from different parts of the country showed the proportion of the five serotypes in the country: O (72.9%), A (19.7%), C (1.4%), South African Territories (SAT) 1 (1.8%) and SAT 2 (4.1 %) (Ayelet *et al*., 2008).

Several FMD outbreaks are reported every year from different parts of the country (Ayelet *et al*., 2008). Table 2 presents seroprevalence of FMD in selected parts of Ethiopia. The frequent occurrences of FMD outbreaks in the country are attributed to the presence of high numbers of susceptible animals, wild and domestic animals sharing common grazing pastures and watering points in areas where wildlife occur, as well as a lack of control of animal movement (Sahle *et al*., 2004). FMD affects cattle managed under all production systems though the impact differs. On a follow up study done in Andassa state dairy farm, Northwest Ethiopia, respectively 15.52% and 2.50% incidence and 2.22% and 2.50% mortality rate were observed among indigenous breed (Fogera) and crossbred (Fogera x Holstein Friesian). During the outbreak, 50% milk yield reduction was recorded in this farm, and also the milk production ten days before the outbreak was significantly higher than that of ten days after the onset of the outbreak (Mazengia *et al*., 2010).

Table 2: Summary of the seroprevalnce of FMD in selected parts of Ethiopia

Zones or districts	Seroprevalence (%)	Production system	Breed of animals	Authors
South Omo	8.18	Extensive/ Pastoralism	Indigenous	Molla *et al*., 2010
Borana	26.5	Extensive/ pastoralism	Indigenous	Sahle *et al*., 2004
Borana	21	Extensive/ Pastoralism	Indigenous	Rufael *et al*., 2008
Afar	5.6	Extensive/ Pastoralism	Indigenous	Shiferaw Jenbere *et al*., 2011
Haramaya	80	Intensive dairy farm	Exotic	Negussie *et al*., 2012
Bahir Dar Zuriya	38.4	Mixed farming system	Indigenous	Negussie *et al*., 2012

Extensive livestock production with low inputs/outputs is the major production system in Ethiopia. Eradication of FMD from the country does not seem to be possible in short time due to several reasons, among others, lack of a good veterinary infrastructure. However, in the meantime vaccination of high-producing livestock minimises production losses that arise from an FMD outbreak. In addition, vaccination of animals that kept in low input/low output systems may be also justified, because the animals produce milk, traction power and the costs of vaccination can be kept low by bulk vaccine production and efficient delivery of vaccination. It is also justified to vaccinate such animals to protect high producing livestock (James and Rushton, 2002).

In Ethiopia, currently there is no national FMD regular vaccination programme devised to control FMD. Only a prophylactive vaccination is practised by some dairy herds containing exotic cattle (Ayelet *et al*., 2009) and ring vaccination during an outbreak around the infected area to curb further spread of the outbreak to other areas. Considering the wide prevalence of serotypes O and A, the National Veterinary Institute (NVI) is producing inactivated vaccine, largely destined for prophylactics in urban and peri-urban commercial dairy herds and export cattle. However, this strategy has not given substantial impact due to limitations in producing sufficient doses and prevalence of other serotypes that are not included in the vaccine formulation. In the Ethiopian market, there have been bivalent vaccine produced by NVI, bivalent vaccine imported from India and quadrivalent vaccine imported from Kenya. The Ethiopian government has envisaged importing millions of polyvalent FMD vaccines with the intention of maintaining and enhancing export of livestock and livestock products in short term and establishing FMD free export zones in long term. NVI is currently formulating a vaccine that incorporate serotypes O, A and SAT 2 (Hassen Belay, personal communication).

In Ethiopia, some dairy farmers vaccinate regularly while other vaccinate only when the rumour of an FMD outbreak is heard in their areas (known as reactive vaccination). When an outbreak occurs in a farm, sick animals are isolated from apparently healthy ones and, expecting a lower severity of the disease and a shorter recovery time, systematic antibiotic and multivitamin administration and wound dressing are done. Unlike the situation in other countries, there is no quarantine and no movement restriction imposed on the farm, and milk is continued to be sold to customers.

There is no published report on the economics of FMD outbreaks at both dairy farm and sector levels and on costs and benefits of vaccination in Ethiopian dairy farms. Literature related to the economics of FMD in Ethiopia is limited and the few available focus on the pastoral production system. A lesson from other developing countries shows regular prophylactive vaccination in dairy cattle is important to avoid losses that emanate from FMD outbreak. Estimation of economic losses can provide a better overall view of the impact of the disease and can contribute in estimating the extent of the losses to be avoided (Dijkhuizen *et al*., 1995). In order to choose among alternative disease control and prevention measures, economic decision making plays a vital role (Dijkhuizen *et al.*, 1995).

2. Materials and methods

This research work consists of two parts. In the first part, the economic loss of an outbreak in dairy farms was estimated at a farm level using a deterministic approach. In the second part, the costs and benefits of different vaccination practices were predicted by a simulation model. Generally, this work contained seven steps; development of simulation model, collection of data from literature, eliciting expert opinions, a field survey in Ethiopia, parameterization, validation of the model and sensitivity analysis and statistical analysis of the economic losses of outbreaks from the questionnaire survey.

Step 1: Model development

Description of the model: Monte Carlo simulation is a computer technique to simulate the reaction of a model under repeated samples and used to generate values from specified inputs distribution (e.g. Normal, Triangular, and Discrete). Stochastic Monte Carlo simulation accounts for variation and uncertainty of variables and gives probability distributions for the consequences of alternative disease control strategies. A farm-level stochastic Monte Carlo simulation model was built in @Risk (Palisade Corporation, Ithaca, NY).

The simulation was done for three scenarios.

Scenario1: No vaccination, in this scenario, we assumed that farmers do not vaccinate their cattle against FMD.

Scenario 2: Reactive vaccination during an outbreak, this scenario assumed farmers vaccinate their animals when there is a rumour of FMD outbreak in the city or nearby villages and vaccination is done at least two weeks prior observation of infection in their farms.

Scenario 3: Prophylactive or preventive vaccination, regular biannual vaccination of cattle was assumed.

Two sub-scenarios were considered under each main scenario with respect to the response of farmers during the phase of FMD outbreaks. Treatment of sick animals with antibiotics, multivitamin or vitamin B complex and wound dressing or not treating sick animals was considered. Several variables were modelled; morbidity, mortality, milk, death, abortion and premature culling losses and treatment and vaccination expenses were included.

The model was constructed in the prototyping approach, in which the development process progressed from simple modelling for one scenario to the complete model. Figure 1 represents the final simulation model used in this study.

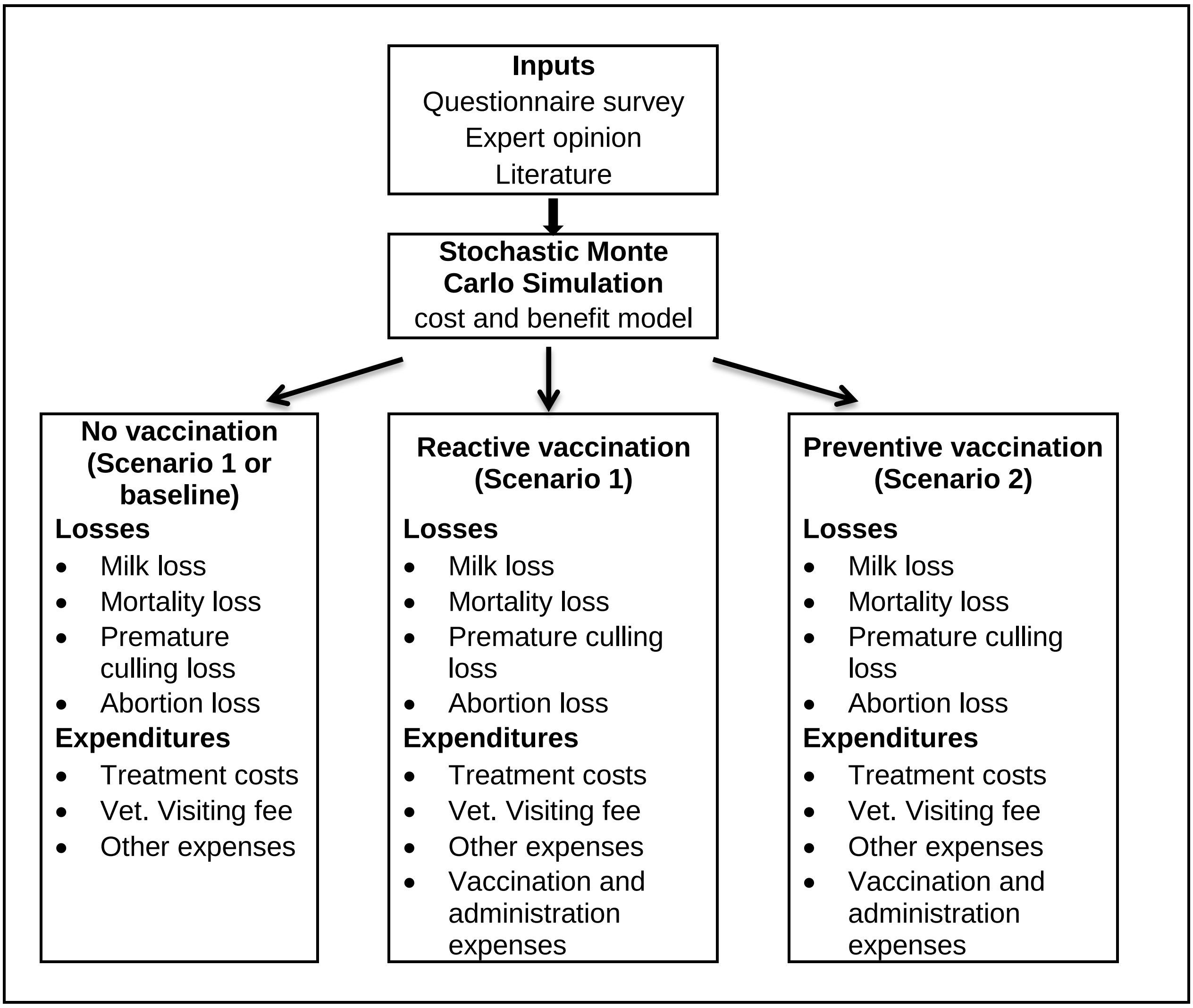

Figure 1. Monte Carlo simulation model of costs and benefits of FMD vaccination practices in commercial dairy farms in Central Ethiopia

Step 2: Collection of data from literature

Published research works done in the study country and other countries were reviewed. However, limited number of published literatures is available on the economics of FMD in Ethiopia and almost all of them focused on pastoral production system. The values of the considered variables obtained from literature were compared with the data generated from the questionnaire survey and when found more realistic, the data from literature were included in the economic model.

Step 3: Eliciting expert opinions

FMD experts were consulted to fill in a questionnaire (Annex 1). This questionnaire was designed to bridge the information gap that arised from shortage of sufficient data generation from the farm survey and literature. Six international and four national experts gave their opinions on the protection level of FMD vaccine, morbidity, mortality, abortion rate, culling rate and abortion rate under different scenarios. The international experts were selected from the list of the participants of 13th International Symposium for Veterinary Epidemiology and Economics and the interview was made on the symposium at Maastricht, The Netherlands. Three of the local FMD experts were people who are teaching at the College of Veterinary Medicine, Addis Ababa University and one of the experts is a researcher in NVI, Bishoftu and they were interviewed during the field work in Ethiopia. Four of them have working experience in FMD through research and farm consultancy.

Step 4: Field survey

The field survey was carried out in Bishoftu (Debre Zeit) town, which is 47 km east of the capital, Addis Ababa. Bishoftu is located at 8°44' latitude and 39°02' longitude with an elevation of 1900 metre above sea level. The topography is generally flat with many small crater hills, mountains and lakes. The climate is characterised to be bimodal with two rainy seasons in a year. The short rainy season occurs between March and May and the main rainy season is during July to September. The mean maximum and minimum annual temperature of Bishoftu are 26^{0}C and 4^{0}C, respectively (National Meteorological Service Agency, 1999). The city is inhabited by nearly 200,000 people. It is the centre of tourism and industries, which includes agro processing factories. Many commercial dairy farms and small dairy holders are found in Bishoftu, who sell their products to agro-processing industries and to cafes and hotels in the capital. Exotic breeds and cross breeds of Holstein Frisian and high productive local breeds such as Borana breed are mainly kept by dairy holders.

To start the field survey, the district animal health officer was interviewed about the number, the location, occurrence of FMD outbreak and vaccination pattern in the last five years and the origin of the vaccines used during this period. The list of farms was made available from an animal health officer in the city, who has been giving home to home artificial insemination and clinical services for several years. Most of the commercial dairy farms with more than 10 dairy cattle in the city were included in the study. Those farmers, who did not record or remember the vaccination status of their animals in the last five years particularly when FMD outbreak occurred, were not included in the survey. Dairy farms were categorised into three groups based on their herd size as small (<10 dairy cattle), medium (10-50 dairy cattle) and large (>50 dairy cattle). In total 31 farms were visited and farmers were interviewed face to face about the history of FMD outbreak and vaccination in their farms in the last five years using a structured questionnaire (Annex 2).

Data management and statistical analysis

The data generated from the survey and the expert opinions were entered into Excel spread sheet and the data were checked for errors of entry, and then imported to SPPS for descriptive and further analysis. The mean milk loss, mean treatment costs, morbidity, mortality, abortion rate, culling rate and other costs related to FMD outbreak were computed for the farm survey. Non-parametric Kruskal-Wallis one way ANOVA was used to compare the means of the variables (milk loss, morbidity, mortality, abortion and premature culling rates, treatment costs and veterinary visiting fee) among the small, medium and large herds and among no vaccination, reactive vaccination and preventive vaccination groups. The significance level was set at $P \leq 0.05$.

Step 5: Parameterization

Input data

The default input values for the considered epidemiological and economic variables were collected from the questionnaire survey and literature (scientific as well as reports and proceeding papers) from Ethiopia and other countries (Table 3). Where sufficient data were not available from the two sources, the opinions of local and international FMD experts were included in the modelling. Input data for the simulation model were based on a questionnaire survey, literature and expert opinion (Table 4). The data obtained from the questionnaire survey have an average and standard deviation and hence, the data were put into a normal distribution. When an average, a minimum, and a maximum were given in the literature, the data were put into a triangular or pert distribution; when only a range was included, data were put into a uniform distribution; and if only an average was calculated, it was used as a fixed value. By stochastic simulation, these distributions from the questionnaire survey, the literature and expertise were combined to estimate the most likely values for the different probabilities in the default calculation.

Calculations in simulation model

The computations done in the simulation model were summarized below.

1. Milk loss per farm (ML):

   $ML = \text{Sum ScMd} * \text{Triang}(MP_{min}, MP_{ML}, MP_{max}) * \text{Normal}(D_{mean}, D_{SD}) * PoC * \text{Uniform}(PoF_{min}, PoF_{max})$,

   Where Sum ScMd is the sum of milk drop of all sick cows on the farm (litre); Triang is triangular distribution, MP is milk price per litre (ETB) and min, ML and max are minimum, most likely and maximum, respectively.

   D is average duration of milk loss or outbreak in the farm (days) with assumed a Normal distribution using the parameters mean and standard deviation (SD);

   PoC is the probability of outbreak in the city and PoF is the probability of outbreak in the farm with uniform distribution.

2. Death loss per farm (DL)

   $DL = Normal(NdA_{mean}, NdA_{SD}) * Normal(PA_{mean}, PA_{SD}) + Normal(NdC_{mean}, NdC_{SD}) * Normal(PC_{mean}, PC_{SD}) * PoC * Uniform(PoF_{min}, PoF_{max})$,

   Where NdA is average number of dead adult cattle per farm, PA is average market price of healthy adult cattle (ETB), NdC is average number of dead calf per farm and PC is average market price of calf (ETB).

3. Abortion loss per farm (AL)

   AL = CL + MLA,

   Where CL is calf loss and MLA is milk loss due to abortion

   $CL = NACw * Normal(PC_{mean}, PC_{SD}) ** PoC * Uniform(PoF_{min}, PoF_{max})$,

   Where, NACw is average number of aborted cow per farm and PC is market price of calf (ETB),

   $NACw=AbR *Normal(PCw_{mean}, PCw_{SD})$, where AbR is abortion rate and PCw is average number of pregnant cows per farm.

   $MLA = Sum\ MLA * Triang(MP_{min},MP_{ML},MP_{max})*Normal(LL_{mean}, LL_{SD}) * PMA** PoC * Uniform(PoF_{min}, PoF_{max})$,

   Where, Sum MLA = the sum of milk yield of aborted cows in the farm, LL = lactation length (days), MP = Milk price/litre (ETB), and PMA = probability of not milked after abortion.

4. Calculation of losses due to premature culling per farm (LPC):

   $LPC = CA * [Normal(PA_{mean}, PA_{SD}) – Normal(PC_{mean}, PC_{SD})] * PoC * Uniform(PoF_{min}, PoF_{max})$,

Where, CA is Average number of culled animals per farm, PA = average market price of healthy adult cattle (ETB), CP = average culling price

$CA=Normal(CuR_{mean}, CuR_{SD})*Norma(NA_{mean}, NA_{SD})$, where CuR is culling rate and NA is average number of adult cattle per farm.

5. Treatment costs per farm (TrC):

   $TrC = NS * Normal(TrSA_{mean}, TrSA_{SD}) *Normal(RTc_{mean}, RTc_{SD}) * PoC * Uniform(PoF_{min}, PoF_{max})$,

   Where NS is average number of sick cattle per farm, TrSA is treatment cost per sick animal and RTc is reduced treatment costs due to the underlying scenario.

   $NS =Normal(TN_{mean}, TN_{SD})*Normal(Morb_{mean}, Morb_{SD})$,

   Where TN is total number of cattle on the farm during the outbreak and Morb is morbidity

6. Veterinary visiting fee per farm (VVF)

   $VVF= Normal(VVFF_{mean}, VVFF_{SD}) * Normal(RVVFF_{mean}, RVVFF_{SD}) * PoC * Uniform(PoF_{min}, PoF_{max})$,

   Where VVFF is veterinary visiting fee per farm and RVVFF is reduced veterinary visiting fee due to the underlying scenario.

7. Other expenditures per farm (EO):
   $OE = NS * Normal(OES_{mean}, OES_{SD}) * Normal(ROE_{mean}, ROE_{SD}) * PoC * Uniform(PoF_{min}, PoF_{max})$,

   Where OES is other expenses per sick animal and ROE is reduced other expenses due to the underlying scenario.

8. Vaccination costs per farm (VC)
   $Pert(VC_{min}, VC_{ML}, VC_{max}) = VP + AC$,
   Where VP is vaccine price per dose and AC is administration cost per dose.

9. Total economic costs per farm (TEC)
   TEC = ML + DL +AL +LPC + TrC +VVF +EO +VC

10. Net benefits per farm
    The net benefit of each scenario is the difference in total economic costs of underlying scenario and baseline scenario (no vaccination and no treatment) or avoidable costs.

Assumptions

1. Commercial dairy farms: farms that keep high production dairy cattle such as Holstein Frisian or their cross bred with local ones (mostly Borana cattle) for milk production, and manage the animals relatively under intensive system.
2. Prophylactive or preventive vaccination; biannual vaccination with quadrivalent vaccine which is imported from Kenya.
3. Reactive vaccination: vaccination that is carried out when there is an outbreak of FMD in the city or in nearby rural villages but at least two weeks before disease noticed in the farm. In the simulation model, the vaccine which is imported from Kenya was assumed.
4. Probability of FMD outbreak: based on the questionnaire survey, in the last five years there was an outbreak every year and hence 100% probability was assumed. Serotypes O, A and SAT 2 are prevalent in Bishoftu. The probability of FMD outbreak in a given farm per year with one of the serotype was assumed based on the field survey and general scientific facts to be in the range of 0% to 100%, which means no outbreak to outbreak every year due to the presence of many serotypes in the area.

Table 3: Default input values for the economic and epidemiologic parameters used in the simulation model and their sources

Variables	**Distribution**	**Mean (most likely)**	**SD***	**Minimum**	**Maximum**	**Sources**
Daily milk yield/cow (litre)	Normal	13.32	4.8	5	23	Questionnaire survey
Lactation period (days)	Normal	328	13			Tadesse and Dessie, 2003
Daily milk loss/cow (%)	Normal	68.23	31.66	27.5	100	Survey
Duration of milk loss (days)	Pert	22.7		16	26	Chowdhury, 1993)
Milk price (ETB)	Triangular	(8.50)		7	10	Survey
Morbidity (%)	Normal	64.32	44.6	11.11	100	Survey
Mortality in young cattle (%)	Constant	20				Radostits *et al*., 2006
Mortality in adult cattle (%)	Constant	2				Radostits *et al*., 2006
Abortion rate (%)	Constant	3.13				Shah *et al*., 2011
Probability of milking after abortion (%)	Constant	50				Assumption
Culling rate (%)	Normal	6.62	11.14	0	30	Survey
Vet visiting fee during the outbreak/farm (ETB)	Normal	648.86	382.06	0	1785	Survey
Treatment cost/sick animal (ETB)	Normal	125.03	89.75	21.25	300	Survey
Other expenses/sick animal(ETB)	Normal	5.39	7.18	0	16.67	Survey
Market price of healthy adult cattle (ETB)	Normal	15,554	5,295	8,000	25,000	Survey
Market price of health male calf (ETB)	Normal	332	118	200	450	Survey
Market price of culled adult cattle (ETB)	Normal	5,786	1,680	3,000	8,000	Survey
Probability of outbreak in the district	Constant	100%				Survey
Probability of outbreak in the farm	Uniform			0%	100%	Survey
Vaccination expenses per dose	Pert	(25)		24	26	Survey
Herd composition						
Young cattle (%)	Normal	19.37	12.35	0	40.21	Survey
Adult cattle (%)	Normal	80.61	12.35	59.79	100	Survey
Lactating cows (%)	Normal	41.52	12.5	21.43	71.43	Survey
Pregnant cows (%)	Normal	20.77	10.18	9.52	50	Survey
Other (heifers, bullocks and breeding bulls) (%)	Normal	25.29	13.43	0	50	Survey
Total No. of cattle/farm	Normal	39	21	4	206	Survey

*SD=standard deviation

Table 4: Initial input values of the economic and epidemiologic parameters used in the simulation model and their sources

	No vaccination		**Reactive vaccination**		**Preventive vaccination**		**Sources**
Treatment	No	Yes	No	Yes	No	Yes	
Scenarios	1.1	1.2	2.1	2.2	3.1	3.2	
Reduced Morbidity	0	0%	50%	50%	80%	80%	Expert and assumption*
SD**	0	0%	10%	10%	15%	15%	
Reduced Mortality	0	40%	34%	60%	55%	90%	Expert and assumption
SD	0	9%	7%	14%	12%	18%	
Reduced Abortion rate	0	50%	33%	45%	59%	75%	Expert and assumption
SD	0	10%	10%	15%	16%	5%	
Reduced culling rate	0	50%	32%	60%	60%	90%	Expert and assumption
SD	0	10%	6%	14%	14%	20%	
Reduced milk loss	0	20%	20%	40%	80%	90%	Expert and assumption
SD	0	5%	5%	8%	18%	19%	
Reduced duration of milk loss	0	25%	25%	38%	40%	50%	Expert and assumption
SD	0	0%	4%	7%	7%	8%	
Reduced treatment expenses	0	0%	20%	20%	30%	30%	Expert and assumption
SD	0	0%	6%	8%	11%	12%	
Reduced other expenses	0	0%	20%	20%	30%	30%	Expert and assumption
SD	0	0%	6%	7%	10%	12%	
Reduced veterinarian visiting fee	0	0%	20%	20%	50%	50%	Expert and assumption
SD	0	0%	5%	6%	12%	12%	
Vaccination frequency	0	0	1	1	2	2	

*Assumptions were made based on the questionnaire survey, literature and own professional experience. **Standard deviation = SD

Step 6: Validation and sensitivity analysis

Validation of the model: to judge whether or not the model mimics reality well the purpose for which it has been developed, internal validation was done. We tried to use correct methods and each question or part of the model had a logical basis, used correct parameters and was correctly written.

Sensitivity analysis: the values of relevant parameters were systematically varied over realistic range to determine their impact on the outputs of the model. We varied one parameter at a time, assuming all other parameters to be at their baseline values.

Ste 7: Calculation of direct losses and expenditures due to FMD outbreak from the questionnaire survey

Economic costs of FMD outbreak per farm were estimated from the survey for each individual farm included in the survey. Losses and expenditures were calculated following a deterministic approach. Calculations of direct losses and expenditures due to FMD outbreak in Bishoftu during the period of 2007 to 2012 were done as follows:

1. Calculation of loss due to milk yield reduction per farm (ML):

$$ML = (M_{pre} - M_{DuO}) * D * MP,$$

Where, M_{Pre} is average milk production of the farm before the outbreak (litre), M_{DuO} is average milk production of the farm during the outbreak/cow (litre), D is average duration of milk loss or outbreak in the farm (days), and MP is milk price/ litre (ETB)

2. Calculation of moortality loss per farm (DL):

$$DL = NdA * PA + NdC * PC,$$

Where NdA is number of dead adult cattle per farm, PA is average market price of healthy adult cattle (ETB), NdC is number of dead calves per farm, and PC is average market price of a calf (ETB)

3. Calculation of abortion loss per farm (LA): CL + MLA

Where, CL is calf loss and MLA is milk loss due to abortion

$$CL = NACw * PC$$

Where, NACw is number of aborted cow per farm and PC is market price of a calf (ETB)

$$LMA = ACw * MPreC * LL * P * PMA$$

Where, ACw is number of aborted cow per farm, MPreC is average daily milk yield per cow (litre), LL is lactation length (days), MP is milk price/litre (ETB), and PMA is probability of milking after abortion (%). Iit was assumed that 50% of aborted cows are milked after abortion.

4. Calculation of losses due to premature culling per farm (LPC):
   LPC = CA * (PA –Pcu)

Where, CA is number of culled animals per farm, PA is average market price of healthy adult cattle (ETB), and Pcu is market price of culled cattle (ETB).

5. Treatment costs per farm (TrC):
   TrC = EAb + EMl +EWm

Where, EAb is price of antibiotics per farm (ETB), EMl is price of multivitamin per farm (ETB), and EWm is costs of wound management per farm (ETB)

6. Other expenditures per farm (EO):
EO = EF + EL + EC

Where, EF is expenses of extra feed per farm (ETB), EL is extra labour per farm (ETB), and EC is costs of construction of isolation pen per farm (ETB)

7. Veterinary visiting fee due to FMD outbreak (EVf): it is the money paid (ETB) per farm for animal health workers who visited the farm during the FMD outbreak.

8. The total economic costs (EC) per farm are the sum of the above losses and expenditures.

   EC = ML + DL + LA + LPC + TrC + EO + EVf

3. Results

4.1 Questionnaire survey

Thirty one dairy farms located in Bishoftu city were included in the questionnaire survey. Twenty three of the visited farms had an FMD outbreak during the study period of September 2007 to September 2012 while the rest did not. Seven farms did not vaccinate their cattle; seven farms did reactive vaccination while nine of them did regular preventive vaccination. An FMD outbreak has occurred every year during the considered study period in Bishoftu. Among visited farms, one farm had FMD outbreak in 2007/08 (2000 E.C), one farm in 2008/2009 (2001 E.C), two farms in 2009/10 (2002 E.C), 12 farms in 2010/11 (2003 E.C) and seven farms in 2011/12 (2004 E.C). Only two farms had two outbreaks during this period, while the other farms had only once.

The average number of cattle kept by dairy farmers in Bishoftu is 39 (Table 5). Eighty one % of the cattle on the farm are adult while the rest are calves up to 6 months. More than 50% of cattle on the farm became sick (average 21.78), at least one animal per farm dead (average 1.35) and almost one cow per farm aborted (average 0.89) due to the FMD outbreak. One animal per three farms were culled prematurely (average 0.3/farm). The average milk loss per cow and duration of milk loss during the outbreak were 8.45 litre/day and 18.65 days, respectively (Table 6). Farm expenditures due to FMD outbreak were attributed to the costs of antibiotics, multivitamin, wound management and supplementary feed and veterinarian visiting fees.

Table 5: Summary of herd composition and number of sick animals during FMD outbreaks in Bishoftu during the period of 2007-2012

	Total per farm		**Sick per farm**	
Categories	**No. (Mean)**	**Standard deviation**	**No. (Mean)**	**Standard deviation**
Cattle on the farm during outbreaks	39.2	20.5	21.78	27.55
Pregnant cows	7.9	12.05	4.46	10.44
Lactating cows	15.8	17.96	8.48	9.79
Heifers	10.48	16.75	6.82	12.19
Female calves	6.66	9.3	3.91	9.16
Male calves	1.41	2.46	0.5	0.76
Bullocks	0.1	0.41	0	0
Breeding bulls	0.52	0.74	0	0

Table 6: Summary of daily milk yield, milk drop, milk price, number of treated animals, treatment and other expenses due to FMD outbreaks during the period of 2007-2012 in Bishoftu

Variables	Mean	Standard deviation	Minimum	Maximum
Normal daily milk yield/cow (litre)	13.32	4.8	5	23
Daily milk drop during the outbreak/cow (litre)	8.45	4.81	1.31	20
Daily milk loss during the outbreak/cow (%)	62.74	27.58	13.89	100
Duration of milk loss (days)	18.65	7.81	7	30
Milk price in 2003 and 2004 E.C (ETB)	7.85	1.45	5	10
Number of treated animals/farm	17.35	24	1	105
Total antibiotic costs/farm (ETB)	1018.57	1693.95	0	8000
Total multivitamin costs/farm (ETB)	352.57	618.97	0	3000
Total costs of wound management/farm (ETB)	437.61	1022.54	0	5000
Extra veterinary fee during the outbreak/farm (ETB)	357	643.56	0	2400
Extra feed costs/farm (ETB)	108	296.04	0	1150
Extra labour costs/farm (ETB)	0	0	0	0
Other costs/farm (ETB)	5.18	24.31	0	114

The output of the descriptive analysis shows that average morbidity rate was 54.75%. Mortality was higher among calves (average 12.43%) than among adult cattle (average 2.65%) and case fatality rates were 23.37% and 6.57%, respectively. Table 7 summarises morbidity, mortality, case fatality, abortion and culling rate per farm.

Table 7: Summary of morbidity, mortality, case fatality, abortion and culling rates due to FMD outbreaks during the period of 2007-2012 in Bishoftu

Categories	**Mean (%)**	**Standard deviation**	**Minimum**	**Maximum**
Overall morbidity	54.75	38.12	3.92	100
Overall mortality	4.01	6.42	0	25
Mortality in young cattle	12.43	30.12	0	100
Mortality in adult cattle	2.65	4.83	0	14.74
Overall case fatality rate	9.61	17.09	0	55.56
Case fatality rate in young cattle	23.37	43.70	0	100
Case fatality rate in adult cattle	6.57	14.95	0	53.85
Abortion rate	13.13	24.33	0	100
Culling rate	2.13	6.58	0	30

The average total economic costs due to FMD outbreak were 45,131ETB per farm which is equivalent to €1,962 (€1=23ETB) (Table 8). Thirty six percent of the loss (average 16,273ETB per farm) was attributed to abortion loss followed by mortality loss (average 32%) and milk loss (average 21%). The average financial loss per milking cow was 2,942ETB (€128).

Table 8: Summary of direct losses and expenditures per farm and per milking cow due to FMD outbreaks during the period of 2007 to 2012 in Bishoftu

Variables	**Direct losses and expenditures per farm (ETB)**				**Direct losses and expenditures Per milking cow (ETB)**			
	Mean	**Minimum**	**Maximum**	**(%)**	**Mean**	**Minimum**	**Maximum**	**(%)**
Milk loss	9,498	245	39,480	21	686	41	2,730	23
Mortality loss	14,333	0	217,560	32	718	0	3,885	24
Abortion loss	16,273	0	133,061	36	903	0	6,173	31
Premature culling loss	2,969	0	26,263	7	493	0	5,853	17
Total losses	**43,073**			95	**2,800**			95
Treatment expenses	1,809	48	16,000	4	114	2	350	4
Other expenses	141	0	2,400	0	21	0	400	0
Veterinarian visiting fee	108	0	1,150	0	7	0	170	0
Total expenditures	**2,058**			5	**142**			4
Total economic costs	**45,131 (€1,962)**			**100**	**2,942 (€128)**			**100**

*****The currency exchange during the study period was assumed as €1=23ETB.

Kruskal-Wallis one way ANOVA analysis showed that the difference among small, medium and large farms were not significant for all considered parameters (p-value>0.05). Similarly, the difference of economic losses among different vaccination status (no vaccination, reactive vaccination and preventive vaccination) was not significant.

4.2. Output of the simulation model

The output of the simulation model shows that the predicted economic costs of no vaccination scenario are higher than the two other scenarios, which are 25,370ETB (€1,103) and 17,610ETB (€766) without (Sc.1.1) and with treatment (Sc.1.2), respectively (Table 9). The highest loss is due to premature culling (10,866ETB=€472) followed by milk drop (8,319ETB=€362) for no vaccination no treatment scenario (Sc.1.1). However, for preventive vaccination the highest cost is attributed to biannual vaccination (1,952ETB=€85). The net benefit increases from the left to the right on Table 9 and Fig. 2. On the other word, the benefit-cost ratio is higher for the preventive vaccination scenario under both sub-scenarios (five and eight, respectively).

Table 9. Simulation output for the comparison of costs and benefits among the three vaccination scenarios and two treatment sub-scenarios

	No vaccination		**Reactive vaccination**		**Preventive vaccination**	
Treatment	No (Sc.* 1.1)	Yes (Sc. 1.2)	No (Sc. 2.1)	Yes (Sc. 2.2)	No (Sc. 3.1)	Yes (Sc. 3.2)
Losses (ETB)**						
Milk loss	8,319	6,651	3,602	2,712	429	296
Death loss	5,334	3,598	2,840	723	999	56
Abortion loss	441	19	13	9	0	0
Culling loss	10,866	5,389	3,563	1,993	693	193
Expenditures(ETB)						
Treatment costs	0	1,543	0	670	0	250
Vet. visiting fee	332	332	266	265	167	165
Other expenses	78	78	34	34	13	12
Vaccination costs	0	0	495	495	1,952	1,952
Economic cost (losses + expenditures) (minimum, maximum)	**25,370** (0, 720,966)	**17,610** (0, 449,175)	**10,813** (0, 395,381)	**6,901** (0, 248,792)	**4,253** (193, 132,473)	**2,925** (193, 82,043)
Net benefit*** (minimum, Maximum)		**7,759** (-19,001, 271,790)	**14,557** (-1,545, 3910,030)	**18,469** (-9,474, 472,174)	**21,117** (-5,481, 610,740)	**22,446** (-5,480, 662,949)
Benefit-cost ratio		**0**	**1**	**3**	**5**	**8**

*Sc. = Scenario, **€1 = 23ETB*** net benefit is the difference between the economic costs under a given scenario and the baseline scenario (no vaccination and no treatment, Sc1.1)

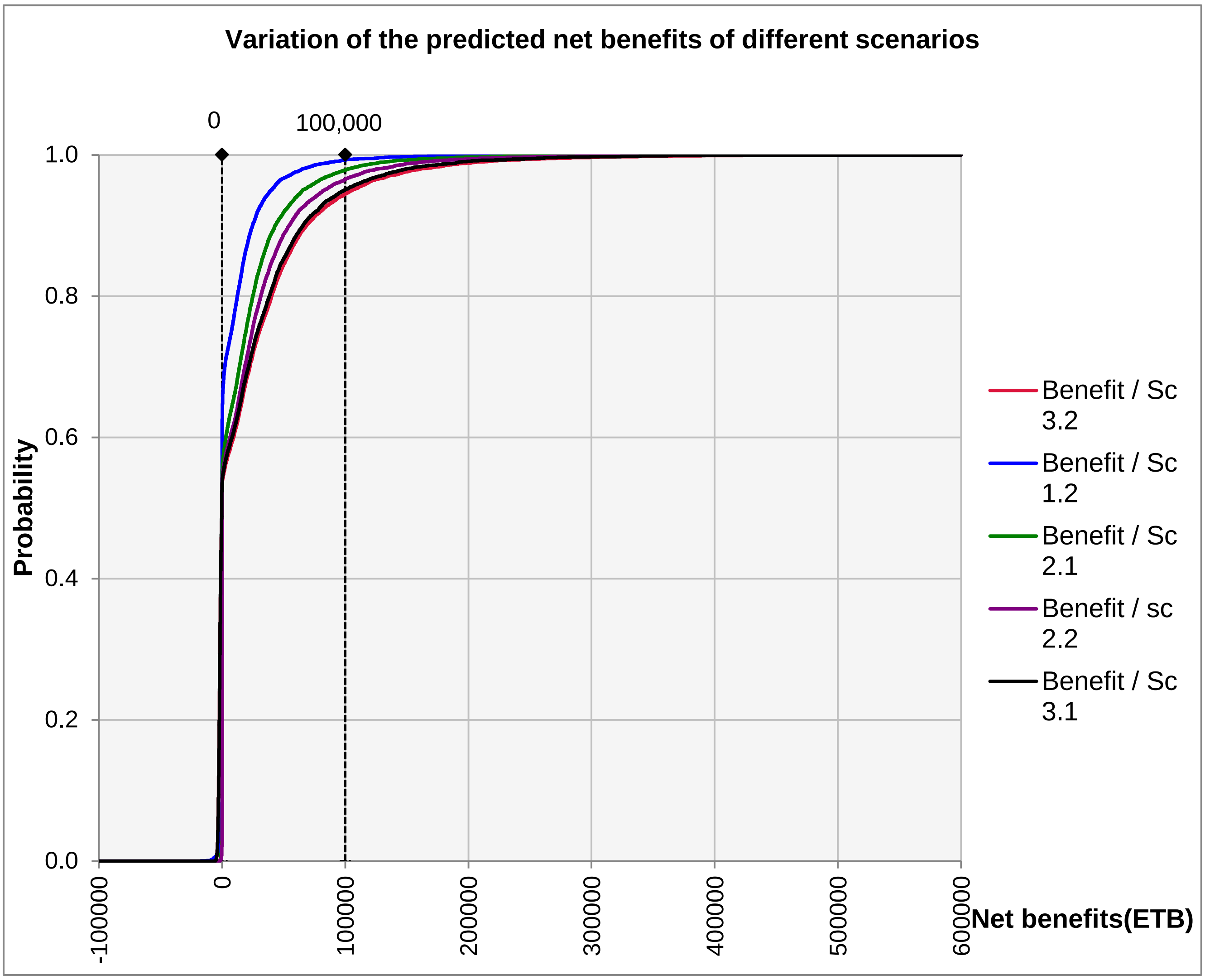

Figure 2. Variations of the predicted net benefits of no vaccination with treatment, reactive vaccination with and without treatment and preventive vaccination with and without treatment

Probability of an outbreak in the farm has the greatest influence on the predicted net benefits of vaccination scenarios. For instance, absence of an outbreak in the farm under the preventive/treatment scenario results in 1992.38ETB loss (Fig. 3), which is slightly higher than the vaccination cost. Number of cattle on the farm during the outbreak, percentage of milk loss reduction due to the underlying scenario, morbidity and culling rates have also substancial influence on the net benefits of vaccination scenarios.

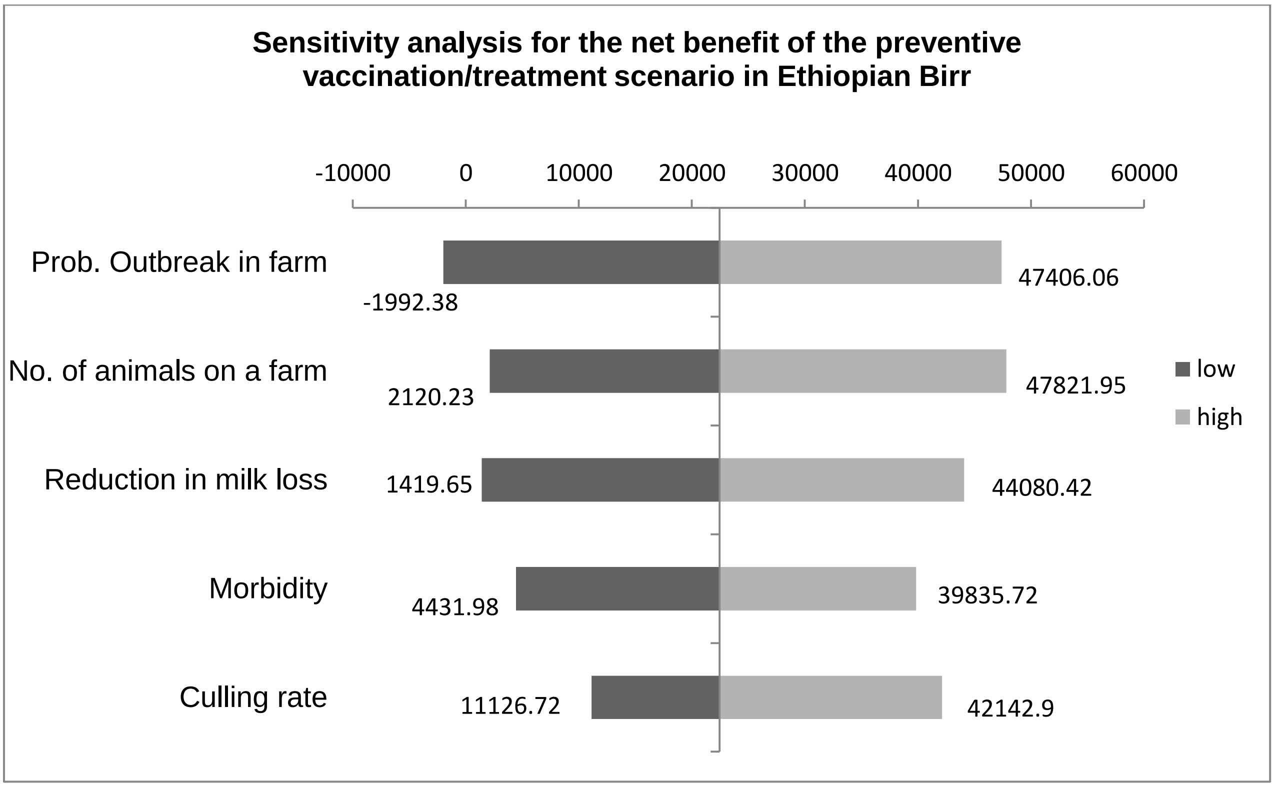

Figure 3. Tornado diagram representing sensitivity analysis for the net benefit of the preventive vaccination/treatment scenario

5. Discussion

This study was carried out to estimate the costs and benefits of FMD vaccination practices in commercial dairy farms in central Ethiopia. The costs and benefits of reactive and preventive vaccinations relative to the no vaccination scenario were predicted using a stochastic Monte Carlo cost-benefit simulation model. Also, the economic losses as a consequence of FMD outbreaks were estimated from a questionnaire survey through a deterministic approach. Assumptions were tried to be made based on reports from other countries and general scientific facts in addition to questionnaire survey and expert opinions. The outcomes of this work could not in any way be perfect; however, it could give insight into losses incurred from FMD outbreak and helps to rank the costs and benefits of different vaccination practices.

The morbidity rate in the current study was 64.23%. In naive animals, morbidity could be as high as 100%. This was evident in FMD outbreak in naive animals in Egypt, where 100% overall morbidity and 80% mortality in calves were observed in 2006 (Abed El-Rahman *et al*., 2006). Since FMD is endemic in Ethiopia, some animals might develop immunity against FMD virus and such animals may not become sick. In previous study, however, relatively lower morbidity than found in the present study was recorded in Haramaya and other places in the country (Negusssie *et al*., 2011). In some farms, calves were immediately isolated from the herd during the outbreak and hence no or low morbidity (also mortality) among such calves were noticed. In this study, a higher mortality rate was observed in calves than in adult cattle. This is in agreement with reports from Ethiopia (Negusssie *et al.*, 2011) and Pakistan (Gorsi *et al*., 2011). This is due to the fact that calves die due to acute myocarditis and also, they easily succumb to secondary bacterial infection (Sáiz *et al*., 2002; Radostits *et al*., 2006). An abortion rate of 13.13% observed in the present study is higher than previous reports from other countries (Khan *et al*., 2006; Gorsi *et al.*, 2011; Shah *et al.*, 2011). Though the virus does not cross placenta, abortion occurs due to high fever (Radostits *et al.*, 2006). Abortion loss is highly important for the dairy sector in that, on one side the farm loses replacing calves and on the other hand, incurs milk loss and medication costs. In general, in the current study, relatively higher morbidity, premature culling and abortion rates than in previous reports were observed. This could be attributed to the research methodology which we followed to identify the disease. Tentative diagnosis based on observation of clinical signs complained by farmers was the diagnostic approach used in the survey to say it was due to FMD.

In the current study the average duration of milk loss in the farm was 19 days. This is in agreement with reports from Eastern part of Ethiopia (Mersie *et al*., 1992) where milk loss of at least 20 days was complained by farmers and from Bangladesh(Chowdhury, 1993) where the disease period for a FMD affected cattle varied from 16 to 26 (average 22.7) days. The milk drop may continue for several months after the outbreak. For instance, there was 3.9% milk drop 60 days post 35 days of quarantine of dairy farms due to FMD outbreak in Kenya (Mulei *et al*., 2001). Milk loss for such long time signifies why FMD is highly important for the dairy sector.

The financial losses incurred by dairy farmers in Bishoftu in the previous FMD outbreaks were substantially high. The farm level average financial loss was estimated to be 45,131ETB (€1,962), which is roughly closer to the average monthly milk sale of a farm in Bishoftu (13.32litre/cow/day*15.8cow/farm*7.85ETB/litre*30days = 49,562.39ETB/farm). This calculation seems to underestimate the actual loss of the outbreaks due to several reasons. First, since farmers do not sell female calves, the market price of a female calf was not available. Therefore, the financial loss due to death of female calf was calculated using the price of a male calf, which is usual lower. Second, this loss does not account for long term effects of the disease on reproductive performance of infected cattle or milk reduction which may continue throughout lactation. Moreover, culling and mortality losses reduce productive life prematurely (Kimani *et al*., 2005; Şentürk and Yalçin, 2008) and, therefore, this quantification of losses does not include these invisible losses too. Third, the opportunity costs of farm personnel for additional working time were not estimated.

In the present study, the momentous direct financial loss was due to abortion (36%). In the calculation of the financial loss due to abortion, we considered financial losses due to calf loss and milk loss throughout the lactation period. Also, it was assumed that 50% of aborted cows are milked during the lactation period. However, the long term effect of abortion on the reproductive performance of the cows and treatment expenses of the abortion were not regarded in the calculation. Observation of highest financial losses due to abortion in the current study is unlike a report from Kenya, in which it was reported that only 1.4% of the direct economic loss was attributed to abortion (Mulei *et al*., 2001), and this deserves further investigation. Mortality (32%) and milk losses (21%) also resulted in substantial losses. However, unlike other reports, direct economic losses due to additional feed costs were low. In Kenya, loss due to additional feed (13.6%) comes second after milk loss (42%). Because of the sloughing of mouth and tongue, sick animals cannot eat dry feed and hence supplementary feeds such as fresh green fodders and concentrates deemed necessary. In addition, there was no extra labour cost; though the workers were busy with additional tasks of nursing sick animals and curbing the outbreak, they were not paid for. In one farm additional cost was incurred due to construction of an isolation pen for sick cattle.

The current study, the Kruskal-Wallis one way ANOVA analysis shows that the variation of losses and expenditures among farms which were not vaccinated, which had undergone reactive and regularly vaccinations were not significant. Lower loss would be expected in regularly vaccinated herds and herds that did reactive vaccination compared to non-vaccinated herds. There could be many reasons for the absence of a significant difference. The outbreak could have been caused by the serotype which was not included in the vaccine. In 2010, serotypes O and SAT 2 were isolated from clinical cases in Bishoftu (Hassen Belay, unpublished). While serotype O is one of the strains included in all FMD vaccines available in Ethiopia, SAT 2 has not been included in the vaccine that has been produced in NVI or imported from India. Isolation of serotype O from the outbreak, if such animals were actually vaccinated, suggests that outbreak was caused by sub-type that is immunologically distinct from the vaccine sub-type. FMD virus serotypes are immunologically distinct from each other so that there is no cross protection among different serotypes and under some cases, within a serotype. Vaccine failure could also be attributed to lack of matching between vaccine and field strains, incorrect administration and poor vaccine efficiency (Grubman and Baxt, 2004; Radostits and Hinchcliff, 2006; Parida, 2009). Consequently, farmers who vaccinated their cattle suffered from severe economic losses alike non-vaccinating farmers. This could discourage farmers to trust FMD vaccines.

The prediction of the simulation shows that regular preventive vaccination is cost effective. The net benefit will further increase if the vaccine will be produced in the country because the vaccine can be produced in a cheaper price than the one imported from Kenya with a foreign currency. Currently, there is a trial to produce a trivalent vaccine that contains the prevalent serotypes (O, A and SAT 2). Within the studied scenarios, the loss is found to be lower if treatment of sick animals is carried out during an outbreak. This is due to the fact that control of secondary bacterial infection can reduce the severity of the disease and shortening the recovery time. The benefit-cost ratio of preventive vaccination combined with treatment during an outbreak is eight. In the simulation model the probability of an outbreak in a given year in the study area was assumed to be 100% based on the fact that there has been outbreak every year in the last five years in the city. Likewise, the probability of outbreak in a given farm per year was assumed to be in the range of 0% to 100%. Such wide range was assumed that because in the survey some farms did not have FMD outbreak in the last five years (0%) and theoretically, an outbreak can occur every year due to the presence of several immunologically distinct FMD serotypes in central Ethiopia (100%).

The predicted net benefits of reactive and preventive vaccination scenarios are highly influenced by the parameter the probability of FMD outbreak in the farm in that year. However, if an FMD outbreak occurs once in four years in a given farm, which is theoretically most likely, the total vaccination costs under preventive vaccination scenario will be 7,808ETB (€340) per farm. Summing up the vaccination costs of four years, treatment expenses and losses associated with an outbreak, the economic cost under the third scenario, preventive vaccination/treatment, is half of the predicted losses incurred under no vaccination/no treatment scenario. Periodic outbreak occurs in endemic areas when susceptible population develop and this could be in the range of 1 to 4 years (Radostits *et al*., 2006). A report from India demonstrates a six-year epidemic cycle (Sharma and Singh, 1993). This fact holds true if only one serotype circulates in the endemic area. However, in areas like Bishoftu, where four or more serotypes are circulating, there is a chance of four or more outbreaks to occur in a given farm in the same year (Kitching, 2002; Radostits *et al*., 2006). Even, if an outbreak occurs every four years, leaving aside the other benefits such as averted long term effects of FMD on reproduction performance, biannual vaccination is cost effective.

Despite rampant FMD outbreaks and commonly carried out vaccination, so far the only applied FMD control strategy in Ethiopia, there was no single report that quantifies the benefits and costs of FMD vaccination in the dairy sector. This piece of work is a first in giving insight into this untouched area. It could be a tool to design extensive FMD control programme and/or convince policy makers to embark national FMD vaccination programme. Importation of FMD vaccines with a price of circa 1.2 USD per dose is cost effective given that the vaccine strains match the field strains in Central Ethiopia and a correct administration procedure is followed. This work also avails information about the benefits of alternative FMD vaccination practices for dairy holders to make good decision regarding which vaccination strategy to follow.

6. Conclusions

The overall short-term farm level direct economic costs associated with the FMD outbreak amounted to 45,131ETB equivalent to €1,962 (€1 = 23ETB). This colossal economic loss within such a short period of FMD outbreak indicates that the control of FMD has paramount importance in the dairy sector in Ethiopia. From an economic point of view, during the previous outbreaks in Bishoftu neither reactive nor preventive vaccination was helpful in preventing clinical disease. This fact was reflected in absence of significant difference in reducing financial losses among farms which had undergone reactive and preventive vaccinations compared to non-vaccinated farms. This finding calls for investigation of why the vaccinations failed to protect clinical disease.

The economic costs due to FMD outbreak were found to be lower if there is regular vaccination with a quadrivalent vaccine imported from Kenya and the costs further decreases if treatment of sick animals is done during an outbreak. Conversely, the predicted net benefit is higher under the preventive vaccination scenario. The economic cost incurred under the preventive vaccination is lower than a loss due to one variable (milk loss or mortality loss or premature culling loss) that will occur if outbreak happens with no prior vaccination (no vaccination/no treatment scenario). Also, the benefit-cost ratio is highest for the third scenario, the preventive vaccination. Hence, biannual preventive vaccination with a quadrivalent vaccine is cost effective for commercial dairy farms given that the vaccine matches the field strains and a correct administration procedure is followed. Biannual preventive vaccination with quadrivalent vaccines and treatment during outbreak is recommended for the dairy sector in central Ethiopia.

7. References

Abed El-Rahman, A.O., Farag, M.A., El-kilany, S., Eman, M.A., El-yazed, M.A., Zeidan, S., 2006. Isolation and identification of foot and mouth virus during an outbreak of 2006 in Egypt. Kafr El-Sheikh Veterinary Medicine Journal 4, 451-464.

Ayelet, G., Gelaye, E., Guitian, J., Sahle, M., Knowles, N.J., Mahapatra, M., 2008. The Status of Foot and Mouth Disease (FMD) in Ethiopia. The Global control of FMD - Tools, ideas and ideals – Erice, Italy Erice, Italy.

Ayelet, G., Mahapatra, M., Gelaye, E., Egziabher, B.G., Rufeal, T., Sahle, M., Ferris, N.P., Wadsworth, J., Hutchings, G.H., Knowles, N.J., 2009. Genetic characterization of foot-and-mouth disease viruses, Ethiopia, 1981-2007. Emerging Infectious Diseases 15, 1409-1417.

Barasa, M., Catley, A., MacHuchu, D., Laqua, H., Puot, E., Kot, D.T., Ikiror, D., 2008. Foot-and-mouth disease vaccination in South Sudan: Benefit-cost analysis and livelihoods impact. Transboundary and Emerging Diseases 55, 339-351.

Bronsvoort, B.M.D.C., Radford, A.D., Tanya, V.N., Nfon, C., Kitching, R.P., Morgan, K.L., 2004. Molecular Epidemiology of Foot-and-Mouth Disease Viruses in the Adamawa Province of Cameroon. Journal of Clinical Microbiology 42, 2186-2196.

Chowdhury, S.M.Z., Rahman, M.F., Rahman, M.B., Rhman, M.M., 1993. Foot and mouth disease and its effects on morbidity, mortality, milk yield and draft power in Bangladesh. Asian-Australasian Journal of Animal Sciences 6, 423-426.

Davies, G., 2002. Foot and mouth disease. Research Veteterinary Science. 73, 195-199.

Dijkhuizen, A.A., Huirne, R.B.M., Jalvingh, A.W., 1995. Economic analysis of animal diseases and their control. Preventive Veteterinary Medicine 25, 135-149.

Doel, T.R., 1996. Natural and vaccine-induced immunity to foot and mouth disease: the prospects for improved vaccines. Revue scientifique et technique (International Office of Epizootics) 15, 883-911.

El-Hussein, A.M., Daboura, A., 2012. Economic impact of an outbreak of foot and mouth disease in Khartoum state, Sudan. Veterinary World 5, 219-222.

Forman, S., Le Gall, F., Belton, D., Evans, B., François, J.L., Murray, G., Sheesley, D., Vandersmissen, A., Yoshimura, S., 2009. Moving towards the global control of foot and mouth disease: An opportunity for donors. OIE Revue Scientifique et Technique 28, 883-896.

Gorsi, M.I., Abubakar, M., Arshed, M.J., 2011. Epidemiology and economics of foot and mouth disease in District Sahiwal, Punjab, Pakistan. YYU Veteriner Fakultesi Dergisi, 22, 159-162.

Grubman, M.J., Baxt, B., 2004. Foot-and-Mouth Disease. Clinical Microbiology Reviews 17, 465-493.

James, A.D., Rushton, J., 2002. The economics of foot and mouth disease. OIE Revue Scientifique et Technique 21, 637-644.

Khan, M.A., Younus, M., Khan, I., Abbas, T., 2006. Some epidemiological aspects of foot-and-mouth disease outbreak in Lahore (Pakistan). International journal of agriculture and biology 8, 300-301.

Kimani, T.M., Mwirigi, J.W., Murithi, R.M., 2005. Financial impact assessment of foot and mouth disease in large scale farms in Nakuru district, Kenya. A Journal of the Kenya Veterinary association 29.

Kitching, R.P., 2002. Clinical variation in foot and mouth disease: Cattle. OIE Revue Scientifique et Technique 21, 499-504.

Kivaria, F.M., 2003. Foot and mouth disease in Tanzania: An overview of its national status. Veterinary Quarterly 25, 72-78.

Leforban, Y., 2005a. Report of a mission on foot and mouth disease in Ethiopia. Proposals for a strategic plan for a control program oriented to the export,. 12-42.

Leforban, Y., 2005b. Report of a mission on foot and mouth disease in Ethiopia. Proposals for a strategic plan for a control program oriented to the export. 12-42.

Mazengia, H., Taye, M., Negussie, H., Alemu, S., Tassew, A., 2010. Incidence of foot and mouth disease and its effect on milk yield in dairy cattle at Andassa dairy farm, Northwest Ethiopia. Agriculture and Biology Journal of North America 1, 969-973.

McInerney, J.P., Howe, K.S., Schepers, J.A., 1992. A framework for the economic analysis of disease in farm livestock. Preventive veterinary Medicine 13, 137-154.

Mekonen, H., Beyene, D., Rufeal, T., Feyisa, A., Abunna, F., 2011. Study on the prevalence of Foot and Mouth disease in Borana and Guji Zones, Southern Ethiopia. Veterinary World 4, 293-296.

Mersie, A., Tafesse, B., Getahun, F., Teklu, W., 1992. Losses from foot-and-mouth disease in a mixed farming area of eastern Ethiopia. Tropical Animal Health and Production 24, 144.

Molla, B., Ayelet, G., Asfaw, Y., Jibril, Y., Ganga, G., Gelaye, E., 2010. Epidemiological study on foot-and-mouth disease in cattle: Seroprevalence and risk factor assessment in south omo zone, south-western Ethiopia. Transboundary and Emerging Diseases 57, 340-347.

Mulei, C.M., Wabacha, J.K., Mbithi, P.M.F., 2001. Short-term economic impact of foot and mouth disease outbreak in a large dairy farm in Kiambu district, Kenya. The Kenya Veterinarian 22, 76-78.

Negusssie, H., Kyule, M.N., Yami, M., Ayelet, G., T, S.J., 2011. Outbreak investigations and genetic characterization of foot-and-mouth disease virus in Ethiopia in 2008/2009. Tropical Animal Health and Production 43, 235-243.

Pamela, H., 1998. Vaccination as a means of control of foot-and-mouth disease in sub-saharan Africa. Vaccine 16, 261-264.

Parida, S., 2009. Vaccination against foot-and-mouth disease virus: Strategies and effectiveness. Expert Review of Vaccines 8, 347-365.

Radostits, O.M., Gay, C.C., Constable, P.D., Hinchcliff, K.W., 2006. Veterinary Medicine. Saunders Elsevier London, Uk.
Roeder, P.L., Abraham, G., Mebratu, G.Y., Kitching, R.P., 1994. Foot-and-mouth disease in Ethiopia from 1988 to 1991. Tropical Animal Health and Production 26, 163-167.
Rufael, T., Catley, A., Bogale, A., Sahle, M., Shiferaw, Y., 2008. Foot and mouth disease in the Borana pastoral system, southern Ethiopia and implications for livelihoods and international trade. Tropical Animal Health and Production 40, 29-38.
Sahle, M., Venter, E.H., Dwarka, R.M., Vosloo, W., 2004. Molecular epidemiology of serotype O foot-and-mouth disease virus isolated from cattle in Ethiopia between 1979-2001. Onderstepoort Journal of Veterinary Research 71, 129-138.
Sáiz, M., Núñez, J.I., Jimenez-Clavero, M.A., Baranowski, E., Sobrino, F., 2002. Foot-and-mouth disease virus: Biology and prospects for disease control. Microbes Infection 4, 1183-1192.
Şentürk, B., Yalçin, C., 2008. Production losses due to endemic foot-and-mouth disease in cattle in Turkey. Turkish Journal of Veterinary and Animal Sciences 32, 433-440.
Shah, K.A., Jan, F.A., Anjum Andrabi, Kaloo, F.A., 2011. Incidence, serotyping and epidemiology of foot and mouth disease in Kashmir. Indian Veterinary Journal 6, article 80.
Sharma, S.K., Singh, G.R., 1993. Cyclic behaviour of foot-and-mouth disease in India. Veterinary Record 133, 448-450.
Shiferaw Jenbere, T., Etana, M., Negussie, H., 2011. Study on the risk factors of foot and mouth disease in selected districts of Afar pastoral area, Northeast Ethiopia. Journal of Animal and Veterinary Advances 10, 1368-1372.
Sutmoller, P., Barteling, S.S., Olascoaga, R.C., Sumption, K.J., 2003. Control and eradication of foot-and-mouth disease. Virus Research. 91, 101-144.
Thomson, G.R., 1995. Overview of foot and mouth disease in southern Africa. Revue scientifique et technique (International Office of Epizootics) 14, 503-520.

8. Annexes

Annex 2. Questionnaire format for interviewing FMD experts

1. What is the protection level of FMD vaccine against disease at farm level (in percentage, in range)?
   Ideal or at laboratory:
   Practical or at field:
   Remarks:
2. What is the most effective frequency of FMD vaccination strategy?
   A. Once/year
   B. Twice/year
   C. Three times per year
   Remarks:
3. Morbidity and severity of FMD outbreak (in percentage, in range)

		Morbidity	Mortality	abortion	Milk drop	Remarks
No vaccination						
Treatment(antibiotic & Multivitamin)						
Reactive vaccination						
Preventive vaccination	Once					
	Twice					
	Thrice					

Annex 2. Questionnaire format for interviewing farmers in Bishoftu, Central Ethiopia

Name of the farm:_________________ District:__________________

Year of establishment:_________

Current No. of dairy cattle in the farm:_____

Breed of dairy cattle: _________________

Table 1: Status of FMD vaccination (vac.) and occurrence

Year (E.C.*)	Vac. status (yes/No)	Vac. type (reactive/ preventive)	Vac. frequency	Origin of the vaccine	Did an outbreak occur in this farm?	Frequency of FMD outbreak	Did an outbreak occur in this area/district?	Remark
2004								
2003								
2002								
2001								
2000								

*E.C. = Ethiopian calendar, 2004E.C.=September 11, 2011 to September 10, 2012.

Table 2: Drop in milk yield due to FMD

Year (E.C.)	Duration of the outbreak	Normal average daily milk yield of the farm (litre)	Average daily milk yield during outbreak (litre)	Milk price per litre	Remark

Table 3: morbidity and mortality

Year:___________

	pregnant cows	lactating cows	heifers	female calf (<6months)	Male calf (<6months)	bullock	Breeding bull	Remark
Herd composition during outbreak								
No. of sick								
No. of dead								
No. of aborted cows								
No. treated animal								
No. culled animal								

Table 4: treatment and vaccination costs

Year: ______________

	No. of treated animal	Costs per treated animal (for all doses)	Total costs			remark
Antibiotics						
Multivitamins						
	No. of animals with wound	No. of treated animal during the outbreak	Costs per treated animal	Total cost		
Wound management						
	Average number of visit without an outbreak (per month)	No. of visit during the outbreak	Fee per visit	Total fee during the outbreak	Extra fee due to an outbreak	
Veterinarian's visiting fee						
	Price per dose	No. of vaccinated animal	Administration costs	Frequency of vaccination per year	Total costs	
Vaccination costs						

Table 5: Purchase and sale of animals

		pregnant cows	lactating cows	heifers	female calf	male calf	Bull	Remarks
Purchase/sale market price	2004							
	2003							
	2002							
	2001							
	2000							
Culling price	2004							
	2003							
	2002							
	2001							
	2000							

Table 6: other costs due to FMD outbreak per an outbreak

		No. of animal on the farm	Total costs	Remarks
Extra feed costs	2004			
	2003			
	2002			
	2001			
	2000			
Extra labour	2004			
	2003			
	2002			
	2001			
	2000			
Other costs	2004			
	2003			
	2002			
	2001			
	2000			