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Jemberu, W. T., Mourits, M., Rushton, J. and Hogeveen, H. 'Cost-benefit analysis of foot and mouth disease control in Ethiopia', *Preventive Veterinary Medicine*.

The final version is available online via <http://dx.doi.org/10.1016/j.prevetmed.2016.08.008>.

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The full details of the published version of the article are as follows:

TITLE: Cost-benefit analysis of foot and mouth disease control in Ethiopia

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JOURNAL TITLE: Preventive Veterinary Medicine

PUBLISHER: Elsevier

PUBLICATION DATE: 25 August 2016 (online)

DOI: 10.1016/j.prevetmed.2016.08.008

Cost-benefit analysis of foot and mouth disease control in Ethiopia

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Abstract

Foot and mouth disease (FMD) occurs endemically in Ethiopia. Quantitative insights on its national economic impact and on the costs and benefits 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 losses and control costs. The total annual costs of FMD under the current status quo of no official control program 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 baseline scenario of no official control program. 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 incidence of the disease was simulated stochastically for 10 years. Preventive mass vaccination 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 targeted 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 economic 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 loss. 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.

Keywords: Control, Cost-benefit, Economic, Ethiopia, FMD, Vaccination

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 growing extensity and intensity of global 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 economic returns of control depend 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. Highly contagious diseases such as FMD are not easily contained and generate serious externalities as they create problems to all livestock owners who are connected to an infected population. These externalities imply that a coordinated FMD control produces a significant amount of public goods, justifying the need for a national public investment (Ekboir, 1999; Forman et al., 2009; Knight-Jones and Rushton, 2013). However, before embarking on large scale control the economic profitability of the control has to be examined and the most profitable option has to be chosen among the available alternatives. 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 policies 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 in

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 in the current Ethiopian situation and on the costs and benefits 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.

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). FMD is clinically and economically more important in cattle and pigs (Kitching, 2002; Mahy, 2005). Because of absence of significant population of pigs the economic importance of the FMD in Ethiopia would primarily be related to cattle and hence this study focuses on the impact of FMD on the cattle production.

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 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 731¹ 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 primarily used for draft power in crop cultivation. The second system is the pastoral² 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 land area (MoARD, 2007). A quarter (169) of the Ethiopian districts has cattle predominantly in pastoral system with comparable number 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 around 0.5 million cattle, either of an exotic breed or crossbreds. 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, household data of 1999-2005 indicated annual commercial gross cattle off-take rates of 16% and 11%; and annual commercial net offtake rates (percent sold minus percent bought) of 8% and 9% in the CLM and pastoral systems, respectively (Negassa and Jabbar, 2008).

¹ Due to merging and separation of districts, the number of districts varies through time. The number referred here is based on the 2007 national population and housing census (CSA, 2008).

² The pastoral system includes also agro-pastoralists who derive part of their income from crop farming.

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 districts, respectively (Jemberu et al., 2015b). This means, for example, about a quarter (24%) of the districts in the CLM system are affected by FMD outbreaks every year. 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.

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.

3. Materials and Methods

To estimate the total annual costs of FMD in Ethiopia, an economic cost 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 an estimation of the incidence of the disease under the defined control strategies. In the next step, the epidemiological estimations were combined with the economic cost 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 break-even analyses for economic returns were carried out.

3.1 Estimation of annual national costs of FMD

According to the framework of Rushton (2009), the economic impact of an animal disease in an endemic situation can be classified by direct and indirect impacts;

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, 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 of time. Other costs such as losses due to using less productive breeds to avoid the risk of FMD and the restriction to market access cannot be exclusively attributed to FMD due to the presence of other relevant diseases. In this study, the annual costs of the disease were, therefore, modelled based on the most important and relatively easily quantifiable costs i.e. the costs related to production losses, control costs and export losses that are specifically attributed to the occurrence of FMD.

3.1.1 Annual production losses

Annual production losses were estimated based upon milk loss, draft power loss and mortality loss. These losses were stochastically estimated for each of the three production systems separately.

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 presented 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 cattle population size, Inc_i the incidence rate of FMD outbreak³ per year, $Morb_i$ the morbidity rate⁴ within an FMD outbreak, $LCPropMorb_i$ the lactating cow proportional morbidity rate⁵, $LCPropCF_i$ the lactating cow proportional case fatality rate⁶, $MilkLLC_i$ 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.

$MortL_i$ 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.

³ A FMD outbreak in this study refers to the occurrence of one or more cases of FMD in a district during an uninterrupted period of time. The occurrence of a case after one month without any FMD cases is considered as the start of a new outbreak.

⁴ Morbidity rate refers to the number of cattle affected by FMD during the course of an outbreak divided by the total number of cattle in the district.

⁵ Proportional morbidity rate refers to the number of affected cattle in a specific category divided by the total number of affected cattle.

⁶ Proportional case fatality rate refers to the number of cattle that died in a specific category divided by the total number of affected cattle.

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 1.

Table 1. Input data to estimate production losses due to FMD in Ethiopia.

Input data	Values / distributions	Description and/or source
Cattle population	Point estimates; ^a CLM = 43,064,610 Pastoral = 13,427,895 MO = 500,000	Derived from CSA annual survey (CSA, 2013) and MoARD (2007).
Incidence of FMD outbreak per year	Binomial (n, p); CLM (542, 0.24) Pastoral (169, 0.39) MO (20, 0.85)	<i>n</i> equals the number districts and, <i>p</i> 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)	<i>n</i> equals the number of cattle per district and <i>p</i> 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 in 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 in oxen	Point estimate; CLM = 0.3128	Based on Jemberu et al. (2014).
Proportional case fatality rate in 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 in oxen	Point estimate; CLM = 0.002555	Based on Jemberu et al. (2014).
Proportional case fatality rate in 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.
Proportional case fatality rate in young stock cattle	Point estimates; CLM = 0.005178 Pastoral = 0.000333 MO = 0.01206	"
Proportional case fatality rate in calves	Point estimates; CLM = 0.023497	"

	Pastoral = 0.009404 MO = 0.041502	
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)	"
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 (^b 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)	"
Price of calves (birr/head)	Triangular (a, b, c); CLM = (500, 1200, 3100) Pastoral = (500, 1200, 3100) MO = (1500, 3000, 4500)	"

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

^bBirr is Ethiopian currency; 1 birr = 0.05 USD.

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. FMD specific impact on export is difficult to estimate as on the one hand it 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 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 tested for FMD using nonstructural proteins serological tests that differentiate infected animals from vaccinated ones. Sero-positive animals 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) data from National Veterinary Institute (NVI). Details of the data and their sources are provided in Table 2.

Table 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	"
Transport cost to export port (birr)	350	"

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.

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

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 recent 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 recent field survey (Jemberu et al., 2014). Details of the control cost data and their sources are provided in Table 3.

Table 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	^a 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 ELISA tests, and sampling cost (10 birr) based on author's judgment
Outbreak investigation cost (birr)	30 350	Authors' calculation - Appendix I

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

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 estimation of the FMD incidence 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.

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., 2014) 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 program (baseline scenario)

This baseline scenario represents the current status quo of no official control program 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 country⁷, 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

⁷ 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-Jjjiga-Berbera route, Hawassa-Moyale route, Jimama Gambela route and Nekemet-Assosa 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 56 000 km² which is equivalent to 37 districts (average area of 1500 km²/district), or roughly 5% districts of the country and hence 5% of the national cattle population.

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 parts 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.

3.2.2 Estimation of the incidence of FMD

Spatially explicit herd based transmission simulation models are often used to simulate 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. A non-spatial transmission model based on SIR framework was attempted to represent the FMD outbreak dynamics for this study but was found less reliable in predicting outbreaks due to scarcity of data to appropriately parametrize the current dynamics (Jemberu, 2016). Given the difficulties of developing valid mathematical transmissions models, this study pragmatically represented 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).

To account for the uncertainty and variation in incidence and disease control parameters, the estimation of the disease incidence was simulated stochastically. In the no official control program (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:

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

Where I represents the yearly incidence of outbreaks, n years in the control period, \rightarrow 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:

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

Where C represents the case incidence during an outbreak, n years in the control period, \rightarrow 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:

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

Where C represents the case incidence during an outbreak, n years in the control period, \rightarrow 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. During this elicitation, experts were reminded to consider the realistic Ethiopian or sub-Saharan animal health service capacity in implementing the strategies. 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 final five experts were used to derive the parameters. Among these experts were one expert with an extensive field disease control experience in Ethiopia, two with field experience on FMD control in Africa, and two experts with field experience of FMD control in other parts of the world.

The judgments of the five experts differed widely. Table 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 the 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 rather combined to a single composite distribution using a discrete uniform probability distribution with equal weights as described by Vose (2008). To account for the correlation between the estimated parameters within experts the simulation 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.

Table 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) ^a	(-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)

^aSome experts think that ring vaccination, if not carefully carried out, may have a negative effect by spreading the disease from affected to unaffected herds by the vaccination personnel, explaining the negative sign.

3.2.2 Outline of cost-benefit calculations

The described incidence simulation and economic costs model were combined to calculate the costs and benefits of each control strategy through time. The time horizon of the analysis was set at 10 years 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 incidence simulation. 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 required 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 I. A summary of the cost estimates are presented in Table 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 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 of the livestock production, the market loss would be minimal and hence was ignored.

Table 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 in the population	Point estimates; ^a 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	Authors' estimation – Appendix I
Costs of outbreak investigation (birr/outbreak)	30 350	"
Costs of movement restriction enforcement (birr/outbreak)	36 000	"
Costs of cold storage (birr)	RVS = 17 061 540 TVS = 19 444 600 PMVS = 29 240 000	" " "
Costs of sero-monitoring (birr/outbreak)	RVS = 42 350	"
(birr/year)	TVS = 502 425	"
(birr/year)	PMVS = 1 522 500	"
Costs of surveillance (birr/year)	825 826	"
Staff capacity building (birr)	5 000 000	"
Discount factor (%)	10	Zhuang et al. (2007)

^aCLM = 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

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 of 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 to be negligible.

3.2.3 Simulation

The stochastic cost-benefit model was created in Microsoft Excel with the add-in @Risk software (Palisade Corporation (2013), Ithaca NY, USA). Key epidemiological inputs (base line 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.

3.2.4 Sensitivity and break-even 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 break-even 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 break-even value is the mean value of a parameter that makes the BCR equal to unity.

4. Results

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). 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. Despite differences in the absolute proportions among production systems, milk losses constituted the majority of costs in all production systems (Table 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 less than 0.1% of the total costs which is related to disease surveillance.

Table 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 losses	1 270 (783-1 958)	93.79	932 (493-1 584)	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.	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 costs	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 costs ^b	4.97 - ^c	0.37	n.a.	n.a.	n.a.	n.a.	4.97 -	8.02
Monitoring costs	0.13 -	0.01	0.09 -	0.01	0.029 -	0.01	0.004 -	0.01
Outbreak investigation costs	1.49 -	0.11	1.10 -	0.12	0.342 -	0.10	0.045 -	0.07
Treatment costs	37 (31-43)	2.74	7.21 (6-9)	0.79	25.40 (20-31)	7.22	4.36 (3-5)	7.04
Total costs (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

^bThe majority of vaccination occurs in the market oriented system, vaccine costs are, therefore, ascribed to this system.

^c Values without CR are deterministically derived.

4.2 Evaluation of alternative FMD control strategies

4.2.1 Epidemiological performance

Based on the incidence simulation, 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 1).

4.2.2 Cost-benefit analysis results

The evaluated control strategies resulted in different scales and distributions of benefits and costs during the analysis period (Figure 2). Because of the skewedness of the distribution of costs and benefits, medians are used to represent the output distributions.

RVS needs a relatively modest investment of a few hundred million birr to begin the control compared to 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, PMVS would need five years for the net return to become positive i.e. the payback period would be after five years.

The cost-benefit analysis results of the alternative control strategies over the 10 years of simulation are presented by the corresponding NPVs and CBRs in Table 7. All the three control strategies resulted in average positive NPVs indicating that they are, on average, economically profitable. The ranges in NPVs are very wide and include negative values which indicate a risk of loss in all evaluated control strategies (Table 7).

Table 7. The distributions of the 10 years NPVs (in billion birr) and BCRs for different control strategies

No.	Strategy	Mean	5 th percentile	Median	95 th percentile	P(NPV<0 or BCR<1)
I. NPV						
1	RVS	1.74	-9.96	2.08	8.69	0.20
2	TVS	4.11	-1.94	4.45	8.73	0.11
3	PMVS	2.03	-4.40	2.51	7.11	0.25
II. BCR						
1	RVS	9.02	-5.66	3.73	31.73	0.20
2	TVS	4.52	0.29	4.29	9.63	0.11
3	PMVS	1.69	0.47	1.63	3.23	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 7). TVS also had the highest median NPV and the lowest probability of resulting in a loss (Table 7). The range of BCR values of RVS includes negative values indicating that its implementation could result in even negative returns. The cumulative BCR distribution curve of RVS in Figure 3 shows three distinct sections corresponding to three clusters of expert judgments about the effectiveness of this strategy. The judgments of the experts for the effectiveness of other strategies were relatively less divergent, resulting in smooth cumulative distribution curves (Figure 3).

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 8).

Table 8. BCRs of the nationally implemented control strategies in the different productions systems

Productions system	Control Strategy	Mean	5 th percentile	Median	95 th percentile	P(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

4.2.3 Sensitivity 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 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 PMVS.

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 break-even analysis was performed. Assuming the same level of reduction in outbreak and case incidences in all production systems, the break-even values for this input parameter were about 2%, 6% and 25% for RVC, TVS, and PMVS, respectively.

5. Discussion

In this study we estimated the total annual costs of FMD in Ethiopia, and analyzed potential economic benefits of introducing a systematic control program. 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.

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 constitute 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 costs. The draft power loss was estimated based on average working days lost per outbreak, although the distribution of working days is not uniform across the year. More working days would be lost when an outbreak occurs during the cultivation season and the impact would be more serious during these times. Most production losses were associated with morbidity. Although the full export costs of the disease were 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 competitiveness, both domestically and internationally, than disease 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 animal health 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.

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 modelling 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 systems. The applied approach is considered as the best possible realistic approach to obtain basic insights in the costs and benefits of the defined control strategies. The approach showed a realistic performance when its output for PMVS 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 profitable in Ethiopia. Despite different degrees of uncertainty and associated risks of loss, all of the proposed control strategies showed, on average, a positive NPV and a greater than unity BCR. Prioritizing the control strategies 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 profitable strategy having the largest median BCR and NPV, and the least uncertainty and risk of loss. It is also epidemiologically more efficient than 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, TVS can be seen as the best strategy to eliminate the endemicity 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 returns 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 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 in reducing the incidence to manageable level. This is an important weakness if the country wants to progress to the next step of disease control, such as achieving disease free status with or without vaccination.

PMVS was the least profitable. It also 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 already had positive net returns 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 are 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.

Given the contagious nature of FMD, its control constitutes a public good which makes a governmental intervention in its control justifiable. Practically the cost of control can be shared by the government and producers. Based on the reasonable assumption that increased production as a result of FMD control will not depress the price of livestock products in Ethiopia, cattle owners will be the primary beneficiaries of the control. It seems therefore logical that farmers would contribute to the control costs like for example by paying the cost of the vaccine. However, within the subsistence systems livestock owners may perceive the cost-benefit outcomes differently as the losses due to FMD are mainly in kind (impacting food security) and do not result in actual reductions of revenues, while the costs for vaccination result in actual expenditures. These expenditures might go beyond the financial resources of most livestock owners' indicating the need for governmental support. This reasoning is supported by the findings of a recent field study (Jemberu et al., 2015a) which indicated that subsistence farmers, specially crop-livestock mixed farmers, have a rather low intention to vaccinate their animals if the vaccine is not given for free.

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 break-even analyses indicated that the break-even 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 that 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). No market effects of control strategies in this study were considered due to lack of data which are needed to undertake

such complex analysis. One reason for this was the practical problem of getting market structure data (e.g. supply and demand elasticities) for the commodity affected by the control such as live animals and draft power. The authors also 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). In the case of milk, 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. 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 impacts 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 profitable. 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 the production impact of the disease and the 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.

Conflict of interest: none

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Appendix I Cost calculations and assumptions for control programs

In the following sections, a detailed description is given of the assumptions which were made to estimate the costs of outbreak investigation, animal movement restriction enforcement, 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 confirmation were estimated at **30 350 birr/outbreak** by accounting for the costs related to the collection of epidemiological data and laboratory samples (18 350 birr/outbreak), and the laboratory confirmation process (12 000 birr/outbreak).

The *costs for collecting epidemiological data and laboratory samples* were derived from the assumption that this task involves a team of 3 personnel (an epidemiologist, a technician, and a local community organizer), which collects data for 5 continuous days, while using one car (car rent 1500 birr/day) with which the team drives 1500 km (fuel costs 4 birr/km) on average. The daily costs of labor of the epidemiologist and technician were based on the daily rate of their gross salary and field allowance (respectively, 450birr/day and 370 birr/day), while the labor provided by the local community organizer was only valued at the level of the daily field allowance (150 birr/day). Given these assumptions, total costs of data and samples collection were equal to 18 350 birr/outbreak.

The *costs related to the laboratory testing* (outbreak confirmation and serotype identification) were based on the assumption of processing 20 quality samples at a cost of 120 birr/sample to test for a single serotype. By testing for the 5 most relevant serotypes (A, O, SAT 1, SAT 2 and SAT3) total laboratory costs equaled 12 000 birr per outbreak confirmation.

ii. Estimating costs of movement restriction enforcement

The costs of animal movement enforcement were assessed at **36 000 birr/outbreak**. Currently there is no Ethiopian 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 was 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 was also assumed that it will require two persons working in two shifts per site during the day until the outbreak dies out (on average after 3 months) with a monthly payment of 1 500 birr to enforce the movement restrictions. Monitoring of the outbreak and lifting of restrictions was assumed to be done by the regular activity of the veterinary services in the districts.

iii. Estimating the costs of vaccination

Costs of vaccination were calculated based on the estimated costs of vaccine (10-16 birr/dose), vaccine distribution and delivery (2 birr/animal), and cold storage (1.7 – 2.9 million birr/year).

Cost of vaccine: A trivalent vaccine was 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). A monovalent vaccine was considered for ring vaccination. The vaccine cost was set equal to the price of imported vaccine as paid by the National Veterinary Institute (NVI). The price of imported vaccine is higher than locally produced vaccine of the same type. The inclusion of the imported price is to account for the fixed costs 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/dose. The price of bivalent and monovalent vaccine was

adjusted accordingly to 13 birr/dose and 10 birr/dose, respectively. These prices were used as most likely input parameter to parameterize a triangular price distribution: the minimum and maximum values were set by varying 50% around the most likely values. Some vaccine wastage (some estimate up to 10%) can be expected for various reasons like missed injections because animals were difficult to handle or failure of cold chain storage. These costs were assumed to be compensated by the costs savings resulting from the fact that not all targeted cattle will be accessed and vaccinated.

Costs of vaccine distribution and delivery: It was assumed that the vaccine deployed from NVI is distributed to each district, where it is subsequently stored and taken to vaccination sites within the districts on a daily basis. The vaccination team was considered to consist of 1 coordinating veterinarian (labor costs 400 birr/day), 2 vaccination technicians (labor costs 270 birr/day) and 1 local community coordinator (labor costs 150 birr/day) using a car (rent 1 500 birr/day) to drive 200 km per day (fuel costs 4 birr/km) and which would be able to vaccinate 2 000 animals per day, resulting in total distribution costs of 3 390 birr/day or 1.7 birr /animal. Other miscellaneous costs like shipping the vaccine from the center to the districts, vaccination organization cost, and cost of other supplies like vaccine syringes, gloves, disinfectants etc. are roughly estimated at 0.30 birr/ animal, resulting in a total vaccine delivery cost of 2 birr/animal.

Note: the cost associated with farmers' time in handling their animals during vaccination was not accounted for.

Costs of cold storage: To store about 80 000 doses of vaccine in a district, a freezer capacity of at least 500 liter is needed, reflecting an estimated price of 20 000 birr. It is roughly assumed that the useful life of freezers is equal to the analysis period (i.e. 10 years). For 731 districts this reflects a 10 years investment of 14 620 000 birr for preventive mass vaccination.

Similar capacity of cold storage is expected to be needed at national or regional level for all strategies. A third and a sixth of this capacity is assumed to be needed at district level for targeted and ring vaccination strategies respectively.

iv. Estimating costs of sero-monitoring

Sero-monitoring is considered to be performed on a yearly base by 15 regional laboratories, by testing 400 random samples from the vaccinated cattle population in their mandate areas. The related costs are the costs for serum sample collection and laboratory testing.

Sample collection: To collect 400 serum samples, a team of 3 persons (total labor costs 970 birr/day) is needed for a period of 10 days, while using a car (rent 1500 birr/day) to drive on average a distance of 2000 km (fuel 4 birr/km). The required sample collection material was valued at 10 birr/sample. Based on these assumptions total cost of serum sample collection equaled 550 500 birr/year (or 36 700 birr/year per laboratory).

Laboratory testing: The 400 samples per laboratory were assumed to be tested by a liquid phase blocking ELISA at an average cost of 162 birr/sample (70% samples would be tested for three serotypes which cost 180 birr/sample and 30% for two serotypes which cost 120 birr/sample), resulting in a total test cost of 972 000 birr/year.

The sum of the serum sample collection costs and test costs represent the total costs for sero-monitoring in the situation of *preventive mass vaccination*, reflecting an amount of **1 522 500 birr/year**. As *targeted vaccination* is considered to involve the vaccination of one third of the cattle population, total costs of sero-monitoring equaled one third of the corresponding costs under preventive mass vaccination (**502 425 birr/year**).

The total costs of sero-monitoring for *ring vaccination*, however, depended on the number of outbreaks, requiring cost estimation per outbreak. In the situation of ring vaccination, serum collection is more concentrated and assumed to require fewer days and travel distance (5 days

and 500 km). The samples will also be tested for a single serotype (60 birr/sample). Based on these assumptions the sero-monitoring costs under ring vaccination were assessed at **42 350 birr/outbreak**.

v. Surveillance costs

The surveillance costs included the cost of outbreak detection and reporting, outbreak investigation, and sero-surveillance. The outbreak investigation costs were already estimated as part of the costs of the disease control program (see *i*). The costs of the remainder activities were estimated to **825 826 birr** per year (in 2013 prices) based on a control plan drafted by MoARD (2006).

vi. Human capacity development costs

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 was considered. A lump sum of **5 million birr** in the first two years of the control programs was assumed to reflect the costs for this capacity development.

Figure 1. The probability of reaching the targeted level (<5%) of national FMD outbreak incidence during the control period under the different control strategies.

Figure 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.

Figure 3. Cumulative distributions of BCRs of the control strategies

Figure 4. Input parameters to which the BCR of the control strategies were most sensitive as indicated by the Spearman rank correlation coefficient.

Fig. 1.

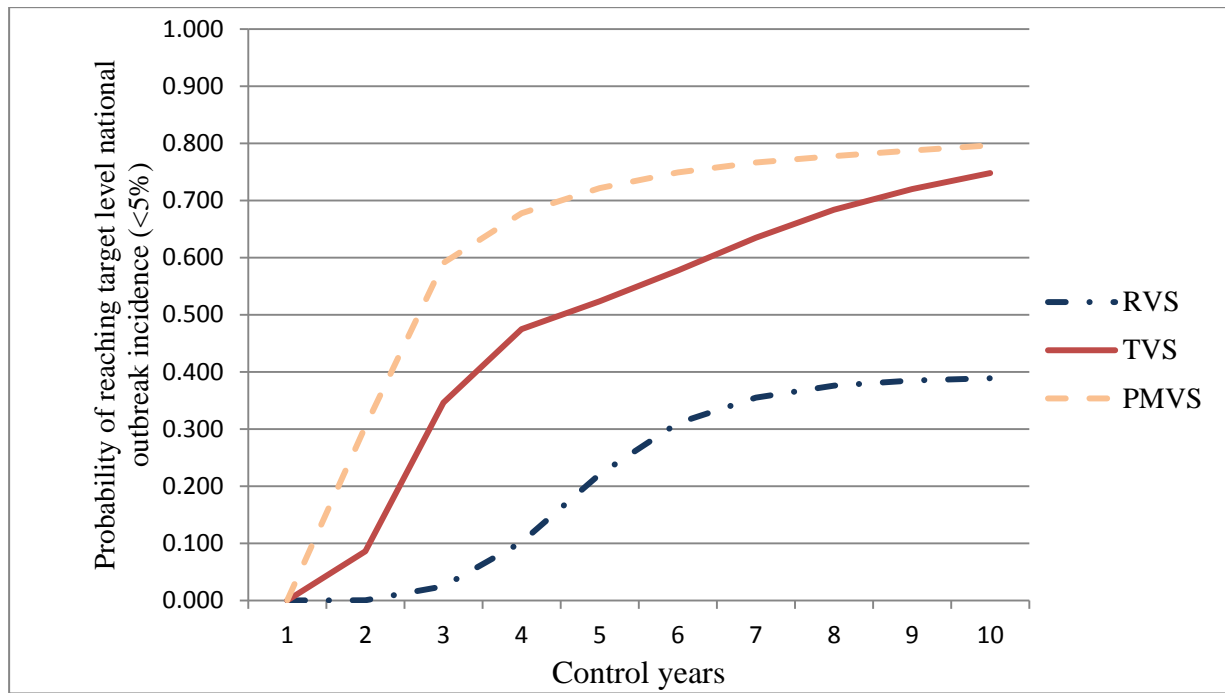


Fig. 2.

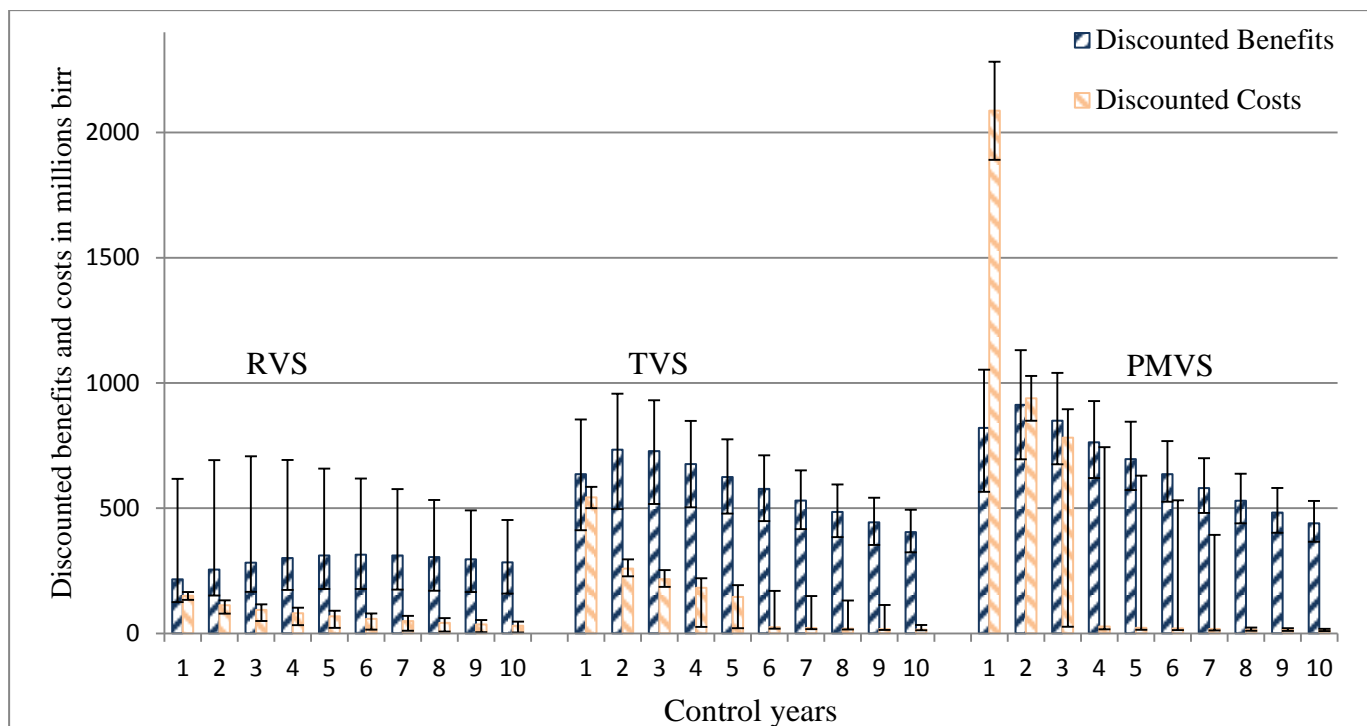


Fig. 3.

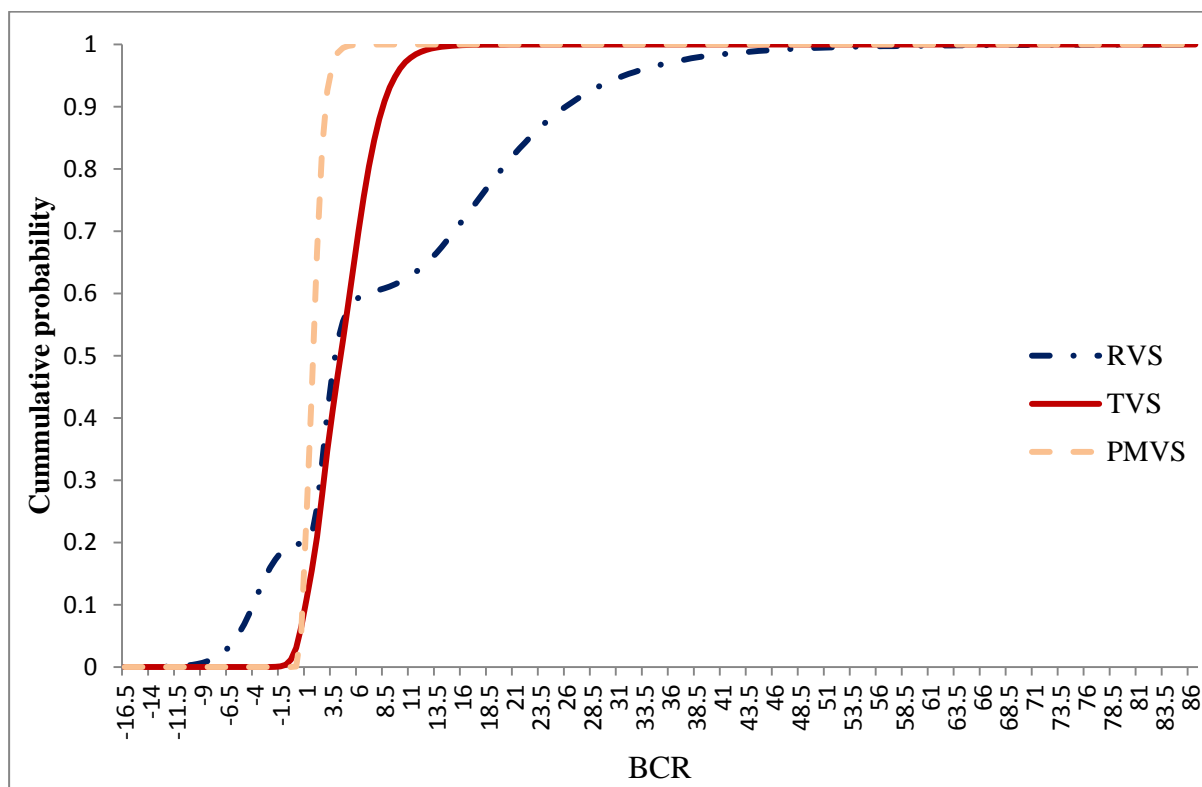


Fig. 4.

