Preventive Veterinary Medicine 202 (2022) 105616

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

Productivity loss and cost of bovine tuberculosis for the dairy livestock sector in Ethiopia

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ARTICLE INFO

Keywords:
Ethiopia
Bovine tuberculosis
dairy cattle
economics
production

ABSTRACT

Bovine tuberculosis (BTB) is endemic in Ethiopia. Although upgraded dairy cattle account for only 1% of the total cattle population, they are the backbone of the marketed milk production in the country. Supported by research data outputs from three years, we report in this paper an estimate of the productivity loss and cost of BTB to the Ethiopian dairy sector in two dairy settings, the urban production system in Central Ethiopia (model 1) and the national upgraded dairy production (model 2). Primary data sources were used (e.g. market survey; three-year longitudinal productivity survey; abattoir survey) as well as secondary data sources. A matrix population model, composed of a population vector representing the herd composition that is repeatedly multiplied with a projection matrix, was developed to simulate the livestock dairy population. The initial herd structure was simulated over 30 years to obtain an equilibrium herd-structure representing an Eigenvector of the projection matrix. We performed an incremental cost of disease analysis by comparing livestock production with and without BTB during a period of 10 years. We assumed a BTB prevalence of 40%. In year ten, the Net present value (NPV) of livestock production in terms of milk, meat and hides was estimated at 154.5 million USD for model 1 and 1.7 billion USD for model 2. Loss of NPV over 10 years was estimated at 12 million USD for model 1 and 131.7 million USD for model 2, representing roughly 7.3% loss in NPV or 219 USD per animal. This is a benchmark against which a national TB control program could be developed in the future to calculate its benefit/cost ratio.

1. Introduction

Bovine tuberculosis (BTB) is an ancient disease with global impact that continues to have devastating impact even in countries with established control programs. As it was contributing to Tuberculosis (TB) cases in humans, many governments started implementing strict control programs in early part of the 20th century with the aim to eliminate the disease in cattle. Such national test and slaughter programs coupled with mandatory milk pasteurization started as early as 1917 in the USA and after the Second World War in most European countries (Olmstead and Rhode 2004). These programs although decreasing the disease prevalence tremendously, were up to this date rarely able to fully eliminate it and showed difficulties in realizing the economic benefits of control strategies. The contributing factors are multiple, including among others the chronic nature of the disease and its long latency, the lack of vaccines, the lack of sensitivity of diagnostic tests, or existing wildlife reservoirs that lead to re-infections (Perez et al. 2011). These control programs are costly and require long-term commitment.

.Total cost for TB surveillance in the USA between 1962 and 2017 was 3 billion dollars (Olmstead and Rhodes 2004). In the Republic of Ireland the costs of an elimination programme, which was inaugurated in 1954 was rounded up to £ 1billion by the year 1988 (Sheehy and Christiansen, 1991). In Spain, the costs of an elimination programme in two districts of the Huesca Province, were at around Pts 2.8 billion for a period of between 1981 to 1993 (Bernues et al., 1997). In Australia, the joint elimination of brucellosis and bovine tuberculosis by a test and slaughter strategy cost ran for 27 years (1970-1997) is estimated at 1 billion USD (Lehane, 1996). Few benefit-cost analyses have been performed in Africa. Abakar et al., using a cattle-human tuberculosis model

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https://doi.org/10.1016/j.prevetmed.2022.105616
Received 14 September 2021; Received in revised form 11 March 2022; Accepted 16 March 2022
Available online 19 March 2022

estimated the cost of elimination of bovine tuberculosis in Morocco at 1.47 to 1.6 billion Euro for a period of 12 to 32 years (Abakar et al., 2017).

In sub-Saharan Africa, such resources are often not available. Around 90% of the human population in Africa live in countries where cattle and dairy cows undergo no or only partial BTB control. However, unlike in the U.S. where less than 5% of the population has regular, direct exposure to cattle, more than half of the population in Africa have close contact with potentially infected animals henceforth are at the threat of acquiring *M. bovis* (Daborn et al., 1996).

Ethiopia is a low-income country, where agriculture remains the backbone of the economy. With 60 million cattle (CSA), the country has the biggest herd in Africa. Livestock contribute to 16.5% of the national GDP, 35.6% of the agriculture GDP and 15% of export earnings (Getabalew et al., 2020). Livestock are an integral part of the majority of the population which is 80% rural, as milk and meat provider, social security, or draft capacity in mixed crop-livestock systems, which remain largely un-mechanized. The dairy livestock sector is facing various challenges, such as poor productivity, a range of endemic infectious diseases, lack of fodder, and lack of veterinary surveillance, health delivery and disease control (Areda et al., 2019; Alemu 2019; Getabalew et al., 2019).

Ethiopia's population is expected to grow from the current 100 million people to 190 million in the next three decades (Mirkena et al., 2018). It is estimated that the demand for milk and meat will increase between 2015 and 2050 by 145% and 257% respectively (Mirkena et al., 2018). Besides importing these products, two options are possible to meet this demand in-country, either increase the livestock population or increase the level of intensification. Both scenarios, and their respective pros and cons have been reviewed and discussed (FAO 2019). An increased cattle population will offer more employment opportunity but will also further exacerbate the existing challenges, increase the risk of zoonosis and Antimicrobial Resistance (AMR) and put more pressure on the environment and rangeland resources. An increased intensification will reduce the cattle number while increasing productivity but diseases linked with intensification might become more prominent. Resources, logistics and level of government commitment will ultimately stir the livestock sector towards one or the other scenario. Currently, upgraded cattle (Holstein Friesian and their crosses) with higher milk potential than local zebus, make up roughly 1% of the total cattle population. However, in recent years, more and more dairy hubs are emerging throughout the country mainly located in and around major regional cities where there is a high demand for milk and milk products.

Bovine Tuberculosis (BTB) is endemic in Ethiopia. Zebu cattle in rural traditional systems show generally a low BTB prevalence. On the other hand, BTB has been shown to be an important disease among upgraded cattle, particularly if kept under intensive husbandry systems where prevalence greater than 70% were observed in large commercial farms in Central Ethiopia (Tsegaye et al., 2010; Firdessa et al., 2012; Biru et al., 2014; Endalew et al., 2017). With the emergence of newly dairy hubs across the country, a valid worry is the spread of BTB to other regions, which might increase the risk for zoonotic TB in the human population. There is currently no national BTB surveillance and control program in place (Areda et al., 2019). Research studies on cost of disease, and cost-benefit analysis are an important pre-requisite before embarking in any type of national or localized intervention strategies to decrease or eliminate BTB (e.g. milk pasteurization, test-and slaughter, animal movement restriction and segregation). To this date, such studies are largely lacking in Ethiopia. A tentative cost estimate was performed by Tschopp et al. (2012) but the study focused mainly on traditional rural cattle system and rough estimates of dairy cattle in Addis Ababa.

This present study on the other hand, focuses entirely on urban dairy cattle and based on field data. It was part of a larger research project on BTB in dairy animals in Ethiopia, where various topics around BTB in the dairy sector were investigated (e.g. disease prevalence, animal productivity, risk factors of disease transmission). In this paper, we report an estimate of the productivity loss and cost of BTB to the Ethiopian dairy sector from an economic model informed by local data.

2. Material and methods

We based our analysis on a matrix population model, which is commonly used for ecological and population dynamic studies (Caswell, 2001). A similar model that has been developed and used since over thirty years for African livestock productivity simulations (Itty, 1991). Details on the model are provided under 2.3.

2.1. Data source

We used various data sources for this study (Table 1). Primary data was collected over 3 years. A longitudinal herd-follow up study of three years (2015-2018) including 24 dairy farms with a total of 1705 cross-bred animals (Holstein-Friesian x zebu) in and around Addis Ababa provided data on herd structure, herd dynamic, cost of live animals and impact of BTB on some productivity parameters (Tschopp et al., 2021a; Tschopp et al., 2021b). Market data on animal product prices (fresh milk, imported powder milk, local cheese, local yoghurt and meat), was collected from August 2017 to March 2018. Data was collected directly at farm level and/or from different sized shops (small street vendor, milk shops, medium supermarkets, large supermarkets) in different towns in Ethiopia (Greater Addis which represented a geographical area of 40 km around Addis, Gondar, Hawassa and Mekele). Descriptive statistics were performed on the market survey data. A p-value <0.05 was considered to be significant. Small price variations were observed but there was no statistical differences by location or by month of the year. Hence, data was pooled as "overall" cost for a specific item in Ethiopia (Table 2). Purchase directly from the farms show a trend of small farm selling cheaper (mean 14.8 ETB; 95%CI: 12.2-17.5) than medium farms (mean 16.2 ETB, 95%CI: 14-18.3) and larger farms (mean 17.8 ETB; 95% CI:15.9-20.6), but statistically not significant ($p=0.518$), hence fresh milk from farm was pooled as an overall average price.

Prices of live animals were recorded on purchase and selling during the entire study time.

Data on animal carcass weight were collected during an abattoir survey assessing the potential impact of BTB on animal weight (Tschopp et al., 2021b).

Additional data used were secondary data from the Ministry of Agriculture, NAHDIC as well as peer-reviewed literature data and national statistical data (Central Statistical Agency CSA Ethiopia, FAOStat). Secondary data was used for incomplete primary data, for data averaging, and for validation of primary data.

Table 1
Summary of data sources used in the analysis.

Parameters	Data source	References
Animal numbers	Secondary	CSA 2018; NAHDIC; MoA; Minten et al., 2020
Herd structure; herd dynamics (e.g. birth rate, mortality, offtakes)	Primary and secondary	Tschopp et al., 2021a; CSA 2018
Milk production	Secondary	Brandsma et al., 2013; Zijlstra et al., 2015; Mirkena et al., 2018; Getabalew et al., 2020; Minten et al., 2020
Price of live animals and animal products	Primary	Tschopp et al., 2021a
Carcass weight	Primary and secondary	Tschopp et al., 2021b; FAOStat
Hide weight	Secondary	FAOStat
% productivity loss due to BTB	Secondary	Meisinger 1970; Bernues et al., 1997

Table 2
Price of live animals and animal products as per productivity study.

			Mean price	95% CI for Mean	SE
Animal products	liquid milk	fresh from shop (1lt)	22.7	20.8-24.5	0.8
		imported (1 lt)	88.7	68.9-108.5	6.2
		local pasteurized 500 ml sachet	13.8	13.0-14.6	0.3
		fresh from farm overall (1lt)	16.5	15.1-17.9	0.66
	powder milk	imported (400 mg)	179.27	148-209.9	14.7
	local cheese (1 kg)		283.3	196-370.5	20.2
	Yoghurt	local (small tub)	17.8	11.7-23.9	2.2
	Meat (1 Kg)		250	202.3-299.2	22.2
Live animals	Female calf		4914	660.5-9168	1738.4
	Male calf		1490.3	1126.8-1866.9	186.4
	Heifer		20'181.8	10'795.1-24'411.6	3174.3
	Breeding cow		17'548.5	15'242.6-18'952.9	940
	Young bull		6625	3619-15'819	3500.6
	Breeding bull		21'500	18'500-25'000	3500

2.2. Productivity Model

We assessed the economic impact of BTB to livestock production in two areas. The first model included Greater Addis Ababa- including Addis Ababa and a 40 km radius around it (Central Ethiopia, urban intensive farming only) and the second model included the upgraded dairy animals at national level. Both models were assessed because in the likely event that the Ethiopian Governement will not be able to conduct sustainable national control programs due to lack of resources, it is important to know priority areas of initial intervention versus a large-scale national intervention. Central Ethiopia remains the principal improved dairy hub and source for animals being sold to the emerging dairy regions. For the first model, we used an estimated animal population of 20-29,000 upgraded dairy cattle (Minten et al., 2020; MoA personal communication, NHADIC personal communication). For the second model, we used an estimated animal population of 600,000 upgraded dairy cattle (estimated from the 1% of the total 60 million cattle; CSA 2018).

2.3. Matrix model of the study dairy herd

A matrix model was developed to simulate the livestock population, which was composed of a projection matrix (P) (Fig. 1) containing annual birth rates, survival rates, persistence rates and offtake rates and a Population Vector (V) composed of the herd composition of female calves, heifers, cows, old cows, male calves, young bulls and old bulls (Eq. 1). The next years (t+1) Population Vector (V_{t+1}) is the product of the current Population Vector (V_t) multiplied by the projection matrix P. This multiplication can be continued over selected time periods required for the economic analysis.

$$(V_{t+1}) = P * V_t \tag{1}$$

The initial herd structure was simulated over 30 years to obtain an equilibrium herd-structure representing an Eigenvector of the projection matrix (Fig. 2). The equilibrium herd structure was then used the estimate the productivity losses from BTB.

P was multiplied with V over ten years from 2015 to 2025 in order to obtain the herd structure, total animals, milk production, and meat production for every year.

In Fig. 3, the main components of a matrix population model are explained. Briefly, in a population projection matrix, the birthrate b is always in the upper right corner, because it is multiplied with the number of adult females A. The diagonal of the matrix contains the proportion of persistence *ps* of the sub-adult S and the persistence *pa* of the adult A. The sub-diagonal contains the survival rates *sy* of the young (newborn) animals Y and the survival rate *ss* of sub-adult animals S.

2.4. Productivity assessment

The asset value of the herd was calculated by multiplying the market value of the respective animal age and sex class.

Milk production was estimated by multiplying the number of calves from the projection matrix by the milk production per lactation in the given year in liters multiplied by the off farm price of milk (17.9 Birr per liter). We assumed an animal milk productivity of 9000 liters per lactation for model 1 (Central Ethiopia) and 4000 liter for model 2

0	0	0.38	0	0	0	0	0	0	0	0	0
0.75	0.50	0	0	0	0	0	0	0	0	0	0
0	0.68	0.73	0	0	0	0	0	0	0	0	0
0	0	0.38	0	0	0	0	0	0	0	0	0
0	0	0	0.2	0	0	0	0	0	0	0	0
0	0	0	0	0.45	0.50	0	0	0	0	0	0
0.11	0	0	0	0	0	0	0	0	0	0	0
0	0.28	0	0	0	0	0	0	0	0	0	0
0	0	0.28	0	0	0	0	0	0	0	0	0
0	0	0	0.71	0	0	0	0	0	0	0	0
0	0	0	0	0.50	0	0	0	0	0	0	0
0	0	0	0	0	0.50	0	0	0	0	0	0

Fig. 1. Projection matrix of the livestock productivity model with annual birth, survival and offtake rates.

No. of animals	Category of bovines
93598	Female calves
126881	Heifers
261090	Cows
93598	Male calves
13676	Young bulls
11158	Adult bulls

Fig. 2. Population vector V of the livestock productivity model that is multiplied with the projection matrix P.

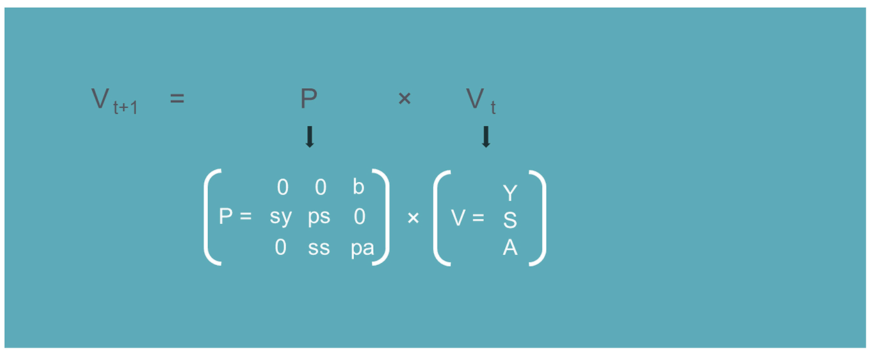

Fig. 3. Population model matrix.

(national) (Zijlstra et al., 2015; Mirkena et al., 2018; Getabalew et al., 2020; Minten et al., 2020).

Meat production was estimated by multiplying carcass weights of the offtake with the value of one kilo of meat costs at 250 Birr. We assumed a weight of 0.12 ton for female breeder, 0.16 ton for male breeder and 0.1 ton for young stock.

For hides, we assumed an equal value of a young and adult animal hide. We assumed a hide weight of 15 kg (0.015 ton) and an average price of 25 Birr per kg of hide, which is 25'000 Birr per ton.

3. Results

3.1. Effect of BTB on livestock productivity

Diseases loss estimates due to BTB were calculated for fertility, milk production and carcass weight. The reduction in the overall parameter value with BTB (e.g. milk production) is dependent on the prevalence of the disease and the percentage loss used for this parameter.

We assume a prevalence dependent decrease of productivity in BTB infected animals. We used a prevalence of 40% (Tschopp et al. 2021a). Using literature data showing that BTB causes a 5% fertility loss (Bernues et al., 1997), a 5% overall loss of carcass (which includes confiscated organs and carcasses as well as live weight loss) (Meisinger 1970) and a 10% reduction in milk production (Meisinger 1970), we computed the productivity loss as:

$\text{Parameter}_{\text{with BTB}} = \text{Parameter}_{\text{Baseline}}$* (1-(BTB prevalence * reduction in the parameter))

The reduction of productivity was calculated as follow (for model 1, intensive dairy, Central Ethiopia):

Reduction in milk production: 9000 liter milk *(1-(0.4*0.12)=8568 liter

The baseline fertility (without BTB) of 0.077847 is reduced by (1-0.4*0.05), resulting in a fertility with BTB of 0.37029.

The base line carcass weight of young animals of 0.07 ton is reduced by a prevalence dependent decrease of 10% resulting in a carcass weight of 0.0672 kg

3.2. Economic evaluation

At an exchange rate of 41 per ETB per USD (www.oanda.com), the cost of BTB to the national improved dairy production is 132 million USD or a loss of 219 USD per cow (Table 3). This is a benchmark against which a national TB control program could be developed to calculate its benefit/cost ratio. For comparison, the societal profitability of a brucellosis mass vaccination program in Ethiopia is 3/1 (Roth et al., 2003), but the effect of brucellosis on fertility is higher than the one of BTB.

Table 3
Calculated NPV loss caused by BTB in livestock for both models over a period of ten years.

	Model 1 (Central Ethiopia)	Model 2 (National)
Asset Value of the herd (ETB) in year 10	554'294'122	13'302'619'642
Annual productivity (ETB) in year 10	987'367'037	10'781'124'725
NPV herd productivity (ETB) in year 10	6'336'173'387	69'185'973'172
Discount rate	0.05	0.05
Loss of Asset Value (ETB) in year 10	17'932'486	430'365'852
Loss NPV (ETB) over 10 years	498'866'746	5'400''90'748
Loss NPV (USD)* over 10 years	12'167'482	131'709'530
Loss NPV/animal (USD) over 10 years	486 (7.30% loss)	220 (7.24% loss)

Exchange rate ETB to USD: 41 (March 2021; www.oanda.com)

3.3. Sensitivity analysis

As the milk production is by far the dominant contribution to the Net Present Value (NPV), we limited the sensitivity analysis to the question of the effect of a change in BTB prevalence on the reduction of the overall loss in productivity (Table 4). We changed BTB prevalence manually from 40% to 0% in steps of 10% and recorded the percent of overall loss of NPV. Results for the urban and national production are shown in Table 5 and Table 6 respectively.

As we used the same effects of BTB on productivity parameters as in (Tschopp et al. 2012) we don't expect different sensitivity results. Cattle productivity is sensitive to fertility, carcass weight and milk production (Meisinger, 1970). Our results show that milk production outweighs financially meat and hide production by far. We refer the reader to our earlier work on the cost of BTB to Ethiopia (Tschopp et al., 2012).

3.4. Limitations of the study

The modeling and calculations performed in this study were subjected to limitations associated with the data sources and with the used matrix model. Secondary data are weak, often based on estimations and extrapolations. There is no accurate figure for examples on the exact numbers of upgraded dairy animals per milk shed. In addition, the milk shed's geographical delimitation varies by author making accurate comparison challenging. National milk production has shown big fluctuations over the last 10 years. In this study, we included the most recent statistical data. Since no context specific figure on loss of productivity due to BTB exist, we relied here on the outdated but classical figures of BTB impact on milk, meat and fertility decrease as described by Meisinger (1970) and Bernues et al., (1997). The used matrix model is appropriate for the simulation of dairy herd productivity (Itty, 1991, 1992). We provided an average estimate of the expected loss from BTB. We did not use probability distributions of productivity parameters because we did not have empirical data of their variability from Ethiopia. Our analysis provide nevertheless a valid information on the magnitude of the losses and consequently of the bracket of intervention cost for a profitable intervention, which is sufficient for planning reasons. Clearly, a very large study with say >5000 animals is needed to estimate empirically the loss of productivity from BTB in Ethiopia.

4. Discussion

Bovine Tuberculosis (BTB) causes substantial economic costs on farms and nations. Industrialized nations have initiated control or eradication programs decades ago with the ultimate goal also to decrease the zoonotic burden of the disease on people. For low-income countries like Ethiopia lacking resources, and plagued by many other health and economic important livestock diseases, launching a national control or elimination programs for BTB is costly, hence feasibility as well as cost-benefit analysis are warranted before embarking into such a program. The decision that initially needs to be made by the Government, is whether the country choses a surveillance, a control or an elimination program. Several factors influences the decision making, including disease prevalence, available resources, logistics and infrastructure, costs involved and who would bear these costs (Government, producers, combination of stakeholders). For instance, disease with high prevalence are difficult to eradicate. A first step is often to initiate strategies to reduce the prevalence and once it has reached a manageable low status, then an elimination strategy is implemented. Combinations of strategies are also possible. Hence, each country will have a unique set of factors to be evaluated prior decisions being taken on which best strategy to adopt (Caminiti et al., 2016).

Table 5
Effect of BTB prevalence on NPV (model 1: Urban production; Central Ethiopia).

BTB prevalence	Loss of NPV (ETB)	Loss of NPV in % of total production
40%	498'866'746	7.3
30%	376'017'293	5.5
20%	251'927'163	3.7
10%	126'590'141	1.85
0%	0	0

Table 6
Effect of BTB reduction on NPV (model 2: national improved dairy production).

BTB prevalence	Loss of NPV (ETB)	Loss of NPV in % of total production
40%	5'400'090'748	7.24
30%	4'070'168'376	5.46
20%	2'726'890'248	3.66
10%	1'370'189'719	1.84
0	0	0

Is an intervention in Ethiopia needed? BTB prevalence in dairy cattle ranges in average between 30 and 40% in Central Ethiopia with some farms reaching prevalence as high as 70% (Firdessa et al. 2012; Tschopp et al. 2021b). Animals are not vaccinated against BTB and there is currently no nationwide surveillance nor control strategy in place (Areda et al., 2019). Dairy hubs have been emerging at fast pace in several regions of the country. Sourcing of animals are often done from Central Ethiopia raising the question of the potential risk of BTB spread into these new dairy centers. Considering the increased demand in animal products by a fast growing population as well as the aim of the Government to increase dairy cattle population and/or increase animal productivity by increasing intensification, BTB becomes a significant disease to be monitored in the future. Our economic model suggests that BTB has a substantial impact on the dairy livestock sector. Unlike the rural setting where the costs of BTB on traditional livestock productivity was negligible (Tschopp et al., 2012), the cost of disease was measurable to dairy farming system in our current study. At national level, BTB causes a loss of 7.2% in herd productivity NPV. This translates into a loss per animal of 220 USD or overall into a loss of 131'709'530 USD. In and around Addis Ababa, our model estimates that BTB causes a loss of roughly 12 million USD at 40% prevalence.

Our results show that there is an urgent need to control BTB in the dairy sector in Ethiopia and avoid further spread of the disease into new emerging dairy hubs in the regions. If prevalence level found in Central Ethiopia shifts to these regions, the costs of BTB (cost of disease and cost of surveillance and control) would be substantial.

Surveillance and control programs are long term ones that need to be sustainable over several years, if not decades. The successful elimination program by test-and slaughter in Australia took 27 years and the costs were shared by the Government and a strong industry (More et al., 2015). An important preliminary requisite for such programs however,

Table 4
Relative proportions of animal products on the overall NPV in the urban and national model.

	Model 1 (Central Ethiopia)		Model 2 (National)	
Animal product	Amount (ETB)	Proportion on NPV	Amount (ETB)	Proportion on NPV
Milk production	628'290'000	98%	6'701'604'379	96%
Meat production	8'952'034	1%	214'804'914	3%
Hide production	2'859'056	0%	68'615'349	1%
Total	640'101'090		6'985'024'642	

is an accurate and efficient animal identification and movement control database as shown in experiences from other countries (More et al., 2015; Palisson et al., 2016). Furthermore, decision on which type of intervention a country will chose will depend on the financial support and who will bear the cost of such interventions. With no Government support, it was shown in Tanzania, that regular cattle testing was financially unmanageable for livestock keepers earning at household level 17.5 USD per year compared to cost of herd testing of 172 USD (Rough et al., 2014). Similarly, in Argentina, producers were entirely covering the costs for BTB control, thus affecting the sustainability of intervention programs (Perez et al., 2011)

5. Conclusion

Looking into the future, Ethiopia is expected to either intensify its farming system or have to increase its dairy animal number in order to meet the rapid population growth demands for animal products. Either scenario will likely lead to increase risks for zoonotic diseases such as BTB and Brucellosis among others. Hence, the importance of developing strong surveillance and control programs. Such programs will rely on disease prevalence level, zoonotic risk of TB, resource and logistic availability, and Government long-term commitment. Decisions on which control intervention strategy is most suited for the context as well as which geographical area should be targeted (e.g. national, regional or localized) will likely have to be made. This paper hence, proposes an economic framework within which alternative programs may be compared and assessed both, before and after implementation.

Funding

This work was funded by the Biotechnology and Biological Sciences Research Council, the Department for International Development, the Economic and Social Research Council, the Medical Research Council, the Natural Environment Research Council and the Defence Science and Technology Laboratory, under the Zoonoses and Emerging Livestock Systems (ZELS) programme, ref.: BB/L018977/1. The funders did not involve in the design of the study and collection, analysis, and interpretation of data and in writing the manuscript.

CRediT authorship contribution statement

RT has designed the research, performed the data analysis and drafted the manuscript. JZ has performed data analysis. GG has collected field data and contributed to drafting the manuscript. JW, and AC provided critical comments to the manuscript. All authors have contributed to the manuscript, and have approved the submitted version.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This work was funded by the Biotechnology and Biological Sciences Research Council, the Department for International Development, the Economic & Social Research Council, the Medical Research Council, the Natural Environment Research Council and the Defence Science & Technology Laboratory, under the Zoonoses and Emerging Livestock Systems (ZELS) programme, ref.: BB/L018977/1. The funders did not involve in the design of the study and collection, analysis, and interpretation of data and in writing the manuscript.

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