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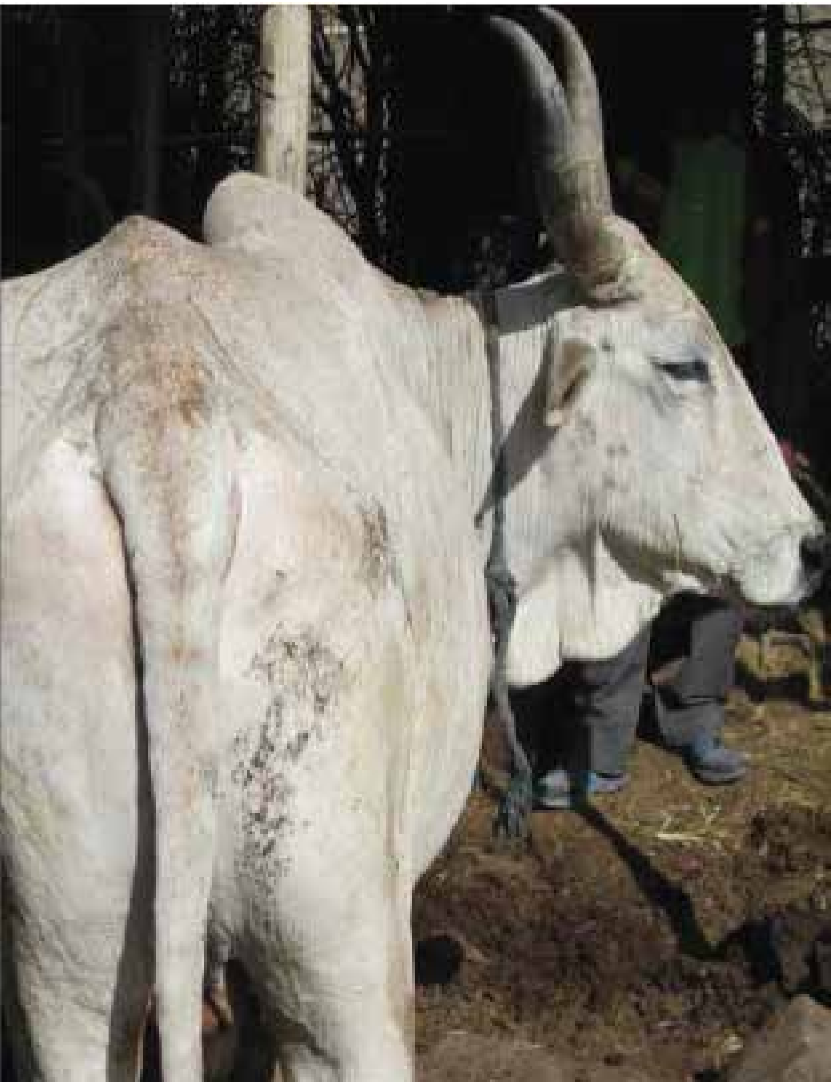

Integrated bio-economic simulation model for traditional cattle production systems in Ethiopia: *Ex-ante* evaluation of policies and investments

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1. Introduction

1.1 Background and justification

Ethiopia has one of the largest livestock populations in Africa. In terms of cattle, in 2013 the national cattle population for Ethiopia was estimated at 54 million heads of cattle distributed among three major livestock production systems: lowland grazing (LG) system (27%), mixed rainfed moisture deficient system (MRD) (27%), and mixed rainfed moisture sufficient system (MRS) (46%) (Ethiopia Livestock Sector Analysis (LSA) report, forthcoming 2016). Despite large livestock resources, Ethiopia is marginally a net exporter of meat, but is a net importer of dairy products while clearly the potential exists for the country to be self-sufficient and major exporter of live animals, meat and dairy products (LSA report, forthcoming 2016). The livestock output levels measured in terms of commercial offtake and the per capita consumption of livestock products in Ethiopia are among the lowest in the world (Negassa and Jabbar 2007). Thus, the exploitation of Ethiopia's livestock potential for national economic growth, household income growth and poverty reduction requires huge investment and policy interventions to increase its productivity level and production. However, the investment resources are very scarce and detailed livestock sector and investment analyses in terms of identifying and prioritizing investment opportunities and constraints in the livestock sector are critical for effective and efficient utilization of the scarce investment resources.

Cattle are one of the most important livestock species kept almost by all farm households in agro-pastoral and pastoral production systems and mixed crop–livestock production systems in Ethiopia; however, the number of cattle owned per household is generally very small and there are also significant number of households who do not own any cattle at all (Negassa and Jabbar 2007). For cattle producers to benefit from the rising demand for cattle and cattle products, they need to have an adequate number of cattle stock that can generate sufficient marketable surpluses of different classes (sex and age) of the cattle herd on a sustainable basis. There is also a need to increase the productivity of the existing cattle herd to improve the competitiveness of the sector. Given the limited land resources for feed and environmental constraints to increasing livestock production, it is particularly important to increase the productivity of the cattle production from the limited existing livestock and land holdings. In this regard, an understanding of the cattle herd growth dynamics is very important to examine the evolution of the cattle herd size and structure over time and identify potential targets for different interventions to increase cattle producers' profits and their volume of participation in cattle and cattle products markets on sustainable basis.

The first task in increasing the output from the cattle sub-sector is to assess the current and future cattle resource base and dynamics and then the potential for profitable commercial offtake. Currently, there are no *ex-ante* analytical and empirical modelling frameworks to guide and prioritize public and private investment decisions to promote the development of cattle sub-sector in Ethiopia. This paper presents an empirical bio-economic cattle herd model to analyse the cattle herd growth dynamics and its economics to inform the various investments and strategies to develop the cattle sub-sector. It builds on previous detailed livestock sector analyses for Ethiopia by International Livestock Research Institute (ILRI) jointly with the Livestock State Ministry of Ethiopia using the LSA. It focuses on a detailed analysis of cattle herd growth dynamics for representative cattle production systems which allows *ex-ante* impact assessment of interventions and thus can inform and guide strategic policy and investment interventions (infrastructure, institutional, technological and cattle management practices) with the potential for significant increase in cattle production, productivity and commercial offtake towards the development of profitable and competitive cattle sub-sector in Ethiopia for beef and dairy production.

1.2 Objectives of the study

The overall objective of this paper is to develop and apply an analytical and empirical modelling framework which integrates a cattle-herd growth model with an economic model for simulating cattle meat and milk production for *ex-ante* assessment of the financial profitability of investment interventions to improve cattle production in mixed and agro-pastoral and pastoral production systems. The specific objectives are:

1. To provide baseline characterization of cattle herd demographics and herd growth dynamics over time in terms of cattle herd growth rate, size and structure and offtake rate for representative cattle production systems and herd size classes; and
2. To evaluate *ex-ante* the technical and financial impacts of combined investment interventions in health and feeds management practices on cattle production.

This paper is organized as follows. The next section provides brief description of the data used in the analysis. Section 3 presents the analytical framework guiding the empirical analysis. The empirical model used is presented in section 4, while section 5 presents the results and discussions. Finally, the conclusions, policy implications and recommendations are presented in section 6.

2. The data and the scope of the study

The detailed discussion of the data sources used in this analysis is documented in the LSA. The data has been obtained from different secondary sources. First, the initial cattle herd size and structure data are generated from the Living Standard Measurement Survey (LSMS) data conducted in 2010/11 jointly by the World Bank and the Central Statistical Authority (CSA) of Ethiopia (LSMS 2010/11) and from Save the Children UK livestock survey data for the pastoral areas of Ethiopia. Second, the cattle demographic data (for example, fertility rates, mortality rates and offtake rates) used to generate parameters for various cattle herd projection matrices are collected using Delphi technique which involved the use of structured questionnaire to collect technical data from the national and international livestock experts. The data collected using Delphi method was validated through panels of expert meetings and discussions. Third, the costs of production for different livestock enterprises and prices for valuation of livestock and livestock products were also obtained from the expert interviews and secondary sources. This study is limited to or focuses on traditional agro-pastoral and pastoral and mixed crop and livestock production systems which account for most of cattle population and livestock dependent population. There is a growing trend towards intensive specialized commercial cattle and poultry production systems, but the scale is still not significant.

3. Analytical framework

The analytical framework for Livestock Sector Investment Policy Toolkit (LSIPT) is based on a dynamic bio-economic simulation modelling. A non-stochastic dynamic herd growth model is used for the projection of livestock population and livestock products (meat, milk, manure and animal traction) over a given time period by the production systems considered. The model allows the simulation of cattle production outputs given inputs used in the cattle production. Then, the dynamic herd model is linked with an economic model to allow the evaluation of financial profitability of cattle production over the same period. The simulation analysis allows the assessment of the technical and financial performance of the cattle sub-sector over time given the inputs used, the existing technologies, market conditions and policies facing the sub-sector. The analysis is conducted at the herd level but the results of the simulation analysis can be aggregated at different levels: production system level, and at regional and national levels. The baseline assessment provides a counterfactual scenario ('without' intervention) against which sub-sector interventions can be evaluated. Thus, it provides the basis for *ex-ante* impact assessments and benefit-cost analyses of various proposed interventions aimed at enhancing the contribution of the cattle sub-sector to farm household income growth, food security, poverty alleviation and national economic growth.

4. Empirical approach

4.1 Stage-structured cattle herd projection matrix model

The population projection matrices are based on Leslie (1945); Caswell (1989); Caswell (2001). Recent applications of population projection matrices to the study of livestock population growth dynamics include: Lesnoff (1999); Lesnoff (2000); Lesnoff *et al.* (2009); Lesnoff *et al.* (2012). In general, there are two types of population projection matrices which are widely used in analysing livestock and plant population growth dynamics over time. The first matrix model is called the Leslie population projection matrix model which classifies the livestock population by age, hence an age-structured matrix model (Leslie 1945). The second matrix model is called the Lefkovitch population projection matrix model which classifies livestock population by their stage of growth or life cycle and hence is called the stage-structured population projection matrix model (Lefkovitch 1965). Each approach has its advantages and disadvantages. The Leslie matrix is considered to be data intensive (for example, requiring age specific demographic data) and mathematically more demanding (due to higher dimensions of matrices) as compared to the stage-structured Lefkovitch matrix model. In terms of application, the stage-structured matrix is more practical, for example, as the utilizations of cattle for different purposes are mainly based on stages of growth (age ranges) rather than being age-specific per se. Both matrix models project the population in *t+1* time period using the initial population at *t* time period and annual transition parameters. For both population projection matrices, the availability of reliable demographic data (e.g. fecundity rates and mortality rates) is critical for the accuracy of the projection of livestock and livestock products. In this paper, the Lefkovitch sex and stage-structured population projection matrix model is used due to its relative computational simplicity and realistic characterization of cattle growth stages.

In a Lefkovitch stage-structured cattle population projection matrix model, the structure of the cattle herd is defined in terms of animal numbers in different age classes and sex cohorts. Thus, the female and male cattle are divided into three discrete growth stages based on age: juvenile, sub-adult and adult. For both sexes, the stage duration for juvenile is one year; for sub-adults and adults the stage duration varies. In general, the stage durations for sub-adults and adult cattle are assumed to differ in accordance with the sex of the cattle and the production system analysed. The projection interval, or time step used for the projection, is one year and the overall cattle population projection time horizon is 20 years. The herd growth model is run by different cattle herd size classes and for representative cattle production systems to see the effects of cattle herd size and production system on cattle herd growth dynamics. In general, growth depends on births, deaths and net offtakes.

Mathematically, the stage-structured deterministic[1] (non-stochastic) population projection matrix model for the analysis of cattle herd growth dynamics considered here is given as a discrete time first-order difference equation:

$$\boldsymbol{n}_{t+1} = \boldsymbol{A}\boldsymbol{n}_{t} \tag{1}$$

Where n_{t+1} denotes the 6x1 state vector of cattle herd sizes by sex and by stage of cattle growth at a time $t+1$; n_t is a 6x1 state vector of cattle herd size by sex and stage of cattle growth at time *t*; and $\mathbf{A}$ is a square 6x6 Lefkovitch annual stage-structured population projection matrix used to analyse cattle population dynamics in discrete time (Lefkovitch 1965). The $\mathbf{A}$ matrix is used to generate a new state variable or vector n_{t+1} and contains the annual transition probabilities derived

1. It is deterministic because the parameters of population projector matrix remain constant over the entire projection time horizon.

based on annual demographic rates (annual fecundity rates, annual mortality rates and annual offtake rates). In general, the Lefkovitch population projection matrix **A** is a generalization of the Leslie age-structured matrix and is given as:

$$\boldsymbol{A} = \left[\begin{array}{cccccc} 0 & 0 & 0.5F_a & 0 & 0 & 0 \\ G_{j,s} & P_{s,s} & 0 & 0 & 0 & 0 \\ 0 & G_{s,a} & P_{a,a} & 0 & 0 & 0 \\ \hline 0 & 0 & 0.5F_a & 0 & 0 & 0 \\ 0 & 0 & 0 & G_{j,s} & P_{s,s} & 0 \\ 0 & 0 & 0 & 0 & G_{s,a} & P_{a,a} \end{array}\right] \quad (2)$$

where F_a is the fecundity of adult female cattle which is the product of annual parturition rate and net prolificacy rate, the subscripts *j*, *s* and *a* denote juvenile, sub-adult and adult cattle, respectively, irrespective of the sex of the cattle and $G_{i,j}$ is the probability that cattle of a given sex in stage *i* will enter the next stage j $(j=i+1)$ in the next time period; and $P_{i,i}$ denotes the probability of an individual cattle of a given sex surviving and remaining (or persisting) in the same stage *i*. The structure and formulation of Leslie and Lefkovitch matrices are similar but the difference is in terms of the columns and matrix entries. In the case of Leslie matrix, the columns of matrix A represent the age of cattle or an animal while in the case of Lefkovitch matrix the column represents the different stages of growth. The other difference between the two is that the matrix entries in the case of Leslie matrix is given in terms of fecundities in the first row which indicate reproductive contribution for different cattle growth stages and survival probabilities (p_i) across the diagonals of the matrix. On the other hand, in the case of Lefkovitch matrix, the fecundities are given in the first row but the survival probabilities are broken down into two: the probability of an individual surviving and moving from class *i* to the stage j ($G_{i,j}$) and the probability of an individual surviving and remaining (or persisting) in the same stage *i* ($P_{i,i}$).

Given the duration of cattle in each stage (d_i) and the stage-specific survival probabilities, the matrix A entries for G_i and P_i are computed using the following formulas (Crouse et al. 1987):

$$P_i = \left(\frac{1-p_i^{d_i-1}}{1-p_i^{d_i}}\right)p_i \quad (3)$$

$$G_i = p_i^{d_i}\left(\frac{1-p_i}{1-p_i^{d_i}}\right) \quad (4)$$

where p_i is the annual survival rate computed below following Lesnoff (2000) based on sex and stage specific demographic rates: annual mortality rate (m_i) and sex-stage specific annual offtake rate (o_i). The survival probability is given as follows:

$$p_i = 1 - m_i - o_i \quad (5)$$

Equation (5) indicates a self-recruiting herd growth model or endogenous population dynamics model where animals are not imported from outside the population for accelerating growth (Lesnoff 2012). Thus, the cattle demographic behaviour is assumed to be influenced mainly by mortality and commercial offtake rates only. Finally, the first order difference equation (1) can be given in vectors and matrix representations as follows:

$$\begin{bmatrix} F_{j,t+1} \\ F_{s,t+1} \\ F_{a,t+1} \\ M_{j,t+1} \\ M_{s,t+1} \\ M_{a,t+1} \end{bmatrix} = \left[\begin{array}{cccccc} 0 & 0 & 0.5F_a & 0 & 0 & 0 \\ G_{j,s} & P_{s,s} & 0 & 0 & 0 & 0 \\ 0 & G_{s,a} & P_{a,a} & 0 & 0 & 0 \\ \hline 0 & 0 & 0.5F_a & 0 & 0 & 0 \\ 0 & 0 & 0 & G_{j,s} & P_{s,s} & 0 \\ 0 & 0 & 0 & 0 & G_{s,a} & P_{a,a} \end{array}\right] * \begin{bmatrix} F_{j,t} \\ F_{s,t} \\ F_{a,t} \\ M_{j,t} \\ M_{s,t} \\ M_{a,t} \end{bmatrix} \quad (6)$$

Where the subscripts in the A matrix denote the stages of cattle growth in *i* and $i+1$ and the multiplication of the fecundity rate by 0.5 is to indicate the 1:1 female to male ratio at birth assumed in the model. Note that matrix A is divided into sex-stage specific blocks as indicated by the horizontal line, the entries in the upper block are for the female cattle, while the entries in the lower blocks are for the male cattle. The basic assumption of the above transition matrix is that only adult females can produce newborn calves hence female dominant matrix model (Lesnoff 1999).

Once the transition matrix A is set-up, the next step in the analysis of cattle herd dynamics is to find out the eigenvalues and eigenvectors of the population projection matrix A. This is because several important parameters which characterize the cattle herd dynamics emerge from the eigenvalue and eigenvector analyses of the transition matrix A. First, the dominant eigenvalue (λ) of matrix A represents the finite (asymptotic) cattle population multiplication rate while log (λ**)** gives intrinsic annual growth rate which is the continuous growth rate per individual cattle herd in the population. Thus, in the long-run the cattle population follows exponential growth rate given by log (λ**)** or**:**

$$\boldsymbol{\lambda = e^{r}} \tag{7}$$

$$\boldsymbol{\lambda^{t} = e^{rt}} \tag{8}$$

Since A is 6X6 square matrix there are six possible eigenvalues and six associated eigenvectors with matrix A. However, the annual rate of increase of population is given by the dominant eigenvalue. The eigenvalues are defined as the solutions to the characteristic equation:

$$det(\boldsymbol{A} - \lambda \boldsymbol{I}) = 0 \tag{9}$$

where *det* denotes determinant and **I** is an identity matrix. The sign of λ indicates whether the herd size (or population) is declining (λ <1), the cattle herd size is staying constant (λ=1**),** or the cattle herd size is increasing (λ >1) in the long-run and shows that potential exists for increased commercial offtake above the current level. For example, λ equal to 1.2 means population will increase by 20% per year and λ equal to 0.93 means the population will decrease by 7% per year in the long-run. Second, the normalized eigenvector (w) associated with the dominant eigenvalue gives the stable stage-structured proportion for cattle herd size. Third, the standardized eigenvectors (v) associated with the dominant eigenvalue of the transpose of matrix A provide the reproductive values of different stages of cattle production as compared to the juvenile, this measures the relative contributions of different stage of cattle growth to long-term growth in cattle herd size.

It is also important to note that several important simplifications of the presentation of the projection matrix model can be made once the dominant eigenvalue and the associated eigenvector are determined. These simplifications are useful for projection purposes. First, there is equivalence between the transition matrix and the dominant eigenvalue and as a result the following relationship holds at equilibrium:

$$\boldsymbol{Aw} = \lambda * \boldsymbol{w} \tag{10}$$

From equation (10) it follows that A is equivalent to λ and the cattle projection equation (1) can be alternatively given as:

$$\boldsymbol{n_{t+1}} = \lambda * \boldsymbol{n_t} \tag{11}$$

For *T* large, λ is also approximated by annual empirical multiplication rate given as the ratio of N_{t+1} to N_t where N represents total herd size for all age groups and sex at a given time. Equation (1) can be also generalized to give the cattle population projection model at any time *t* given the initial herd size and stable herd proportion as:

$$\mathrm{n_t = n_0} * \lambda \mathrm{t} * \mathrm{w_{n0}} \tag{12}$$

Where n_t is a vector of cattle population at time *t*; n_o is scalar and denotes the initial cattle herd size; λ is the dominant eigenvalue and w is the normalized eigenvector associated with the dominant eigenvalue and denotes stable stage proportions. Similarly, given the stable sex and stage distribution, and asymptotic cattle growth rate, the total commercial live cattle offtake for cattle with i^{th} sex in j^{th} growth stage at any time *t* denoted as $0_{ii,t}$ can be obtained using the following commercial offtake function:

$$O_{ij,t} = O_{ij} * n_o * \lambda^t * \boldsymbol{w} \tag{13}$$

Where $O_{ij,t}$ is a vector of commercial offtake of the i^{th} sex in j^{th} growth stage at *t* time. The total carcass equivalent commercial live cattle offtake at a given time period is given by aggregating the carcass offtake rates across sex and stage classes. This shows the quantity of commercial offtake with constant cattle growth rate and stable stage-structure w. Similarly, the milk and other products production is also obtained by using appropriate offtake rates for each product.

It is also possible to compute steady-state commercial offtake which is characterized by equilibrium situation where the growth rate is zero. The simulation analysis to see the effects of different interventions is usually conducted for steady state situation to avoid bias due to changes in cattle herd size and structure. For a steady-state situation with λ equal to 1, the cattle herd projection model given in equation (11) is modified as:

$$\boldsymbol{n}_t = \boldsymbol{n}_o * \boldsymbol{w} \tag{14}$$

and accordingly the commercial offtake function can be also modified as:

$$O_{ij,t} = O_{ij} * n_0 * \boldsymbol{w} \tag{15}$$

The steady state offtake λ is a constant, while the cattle herd size or population remains constant over time. This is a desirable management strategy whereby a regular offtake is made thereby producing regular income and returning cattle population to stable size and structure. This is important particularly when there is a need to limit the size of cattle due to the need to match the livestock numbers to available feed resources. This objective is achieved through numerical manipulation of the transition matrix whereby the λ is equated to 1 and the offtake rates are choice variables selected using non-linear optimization technique.

One of the important goals of the analysis of cattle herd growth dynamics is to determine what stages and what demographic rates are most likely causing the increase or decrease in the cattle herd. This is important because resources are limited so priority areas of development and research interventions need to be identified. For this purpose, sensitivity and elasticity analyses are made in order to assess the impact of changes in cattle demographic factors (reproductive rates and mortality rates) on the long-term cattle growth rate (λ). The sensitivity is calculated from the elements of the right and left eigenvectors (w and v, respectively) as follows (de Kroon et al. 1986):

$$S_{ij} = \frac{\partial \lambda}{\partial a_{ij}} = \frac{v_i w_i}{\langle w, v \rangle} \tag{16}$$

Where v is the left eigenvector associated with A, and $<w, v>$ is the scalar product of vectors w and v. The sensitivity analysis estimates the impact of an absolute change in the demographic rates on population growth rate. High sensitivity values indicate that little intervention could have a large impact in cattle population growth. However, the problem with the sensitivity analysis is that the values of sensitivity analysis cannot be compared among different demographic parameters when different scales or units are used. Therefore, instead, the unit-free elasticity is calculated from the elements of the transition matrix (a_{ij}) in A, the population growth rate, and the elements of the right and left eigenvectors (w_i and v_i) as follows:

$$\varepsilon_{ij} = \frac{a_{ij}}{\lambda} \frac{v_i w_i}{\langle w, v \rangle} = \frac{\partial \log(\lambda)}{\partial \log(a_{ij})} \tag{17}$$

where $\langle w,v \rangle$ is the scalar product of the two vectors defined as before. The elasticity analysis estimates the effect of a proportional change in the demographic rates on population growth rates. Elasticities are unit-less, represent proportional contribution to λ and are often considered easier to interpret than sensitivities, particularly, when the matrix elements are measured in different units or operate on different scales (e.g. survival rates and fecundity rates) (de Kroon et al. 1986).

Since the elasticities are proportions they all sum to one and this property allows us to assess the proportional contribution of each matrix element to λ. For each column of the matrix A, which correspond to the individual stage, the elasticity values across the rows can be summed to assess how the different stages in cattle production contribute to the cattle growth rate. Similarly, for each row, the sum of elasticity can be made across the columns to assess the relative contribution of the different demographic rates to cattle growth rate (for example, fecundity rates and mortality rates). Thus, the analysis of the elasticity helps to identify the stage where the smallest changes in demographic rates will produce the biggest change in the population growth rate and hence this helps to prioritize intervention efforts. Different scenario analyses can also be conducted to take into account the degree of uncertainty and/or variation in the input parameters in the projection matrix. For scenario analysis, different values for demographic rates can be used to reflect uncertainty and variation. It is also important to note that the asymptotic multiplication rate of all or part of the population depends on the female demographic rates, hence, female dominant herd model (Lesnoff 1999). It is indicated that the male demographic rate affects the sex-ratio in the population and the age structure of the male cattle herd only.

The cattle herd projection model used here allows to estimate various outputs from the cattle production over time: commercial offtake of live cattle (and its meat equivalents), milk, manure and draft power production by different classes of cattle, herd sizes and production systems. In order to measure the productivity, feed requirements and output, the special case of a steady state (or zero growth) herd, achieved by adjustment of the offtake rates is used. This is particularly important to obtain unbiased estimate of treatment effects. The steady-state is obtained by the re-parameterization of the population projection matrix A such that the dominant eigenvalue of the re-parameterized matrix A is equal to 1. The parameterizing is done by changing the offtake rates numerically.

4.2 Economic model

The economic model to analyse the financial and economic profitability of cattle production 'with' and 'without' policy and investment interventions is based on a capital budgeting approach. This approach requires a stream of costs and benefits to be reduced to a comparable present worth using the process of discounting as outlined in Gittinger (1982).

Baseline assessment of financial profitability

The financial viability of cattle production 'without' intervention is assessed by cattle herd size classes and production systems using the present value (PV) of annual gross margins (GM) generated from cattle production over the time horizon of 20 years. The GM is given as the difference between the total revenue (TR_t) of multiple outputs (meat, milk, manure, or draft power depending on the cattle production system considered) generated from cattle enterprise and variable costs (VC_t) associated with cattle production for stable cattle herd size and structure. The major variable costs include: costs of veterinary drugs, medicine and mineral supplements. The cattle management affects the reproduction rates and mortality rates which in turn affects the performance of cattle in different production systems by affecting the rate of cattle herd growth and potential offtake rates (meat, milk, manure and draft power). The herd growth model is linked to the economic model whereby the offtakes from the herd growth model are monetized.

Mathematically, the present value of the gross margin ($PVGM$) for a given herd size class is given as:

$$PVGM = \sum_{t=0}^{T} \frac{(TR_t - VC_t)}{(1+\delta)^t} = \sum_{t=0}^{T} \frac{GM_t}{(1+\delta)^t} \tag{18}$$

where T is the assumed relevant planning time horizon in years; δ is the discount rate (10% assumed); GM_t is the annual gross margin accrued in period *t*. In general, the GM represents return to the farm household's labour, land and capital in cattle production and is a farm gate measure of the gross domestic product (GDP) for cattle. In general, the higher the $PVGM$ the better. Furthermore, if availability of data allows, the net profit for cattle production can be obtained as the difference between the GM and the fixed costs. The net profit indicates the extent to which the cattle producers are earning normal or excess profit and thus reflects the level of competition and risk existing in the cattle sub-sector. However, due to lack of data on the fixed costs for individual farm households it was not possible to compute the net farm income or net profits for the cattle production systems.

The life cycle of livestock production differs by livestock species and production system due to the difference in the biology and objectives of livestock production in different production systems which affect the length or time horizon of the project. In such situations, when project time horizons are different, when comparing the *GM* for different livestock enterprises or crop enterprises, it is important to analyse the *GM* in terms of annual equivalent cash flows. Thus, the annualized present value of gross margin (*APVGM*) is given as:

$$APVGM = PVGM * \frac{\delta * (1+\delta)^t}{(1+\delta)^t - 1} \tag{19}$$

Once the *APVGM* is derived it can be combined with the geographic information system (GIS) data and cattle population data to generate the cattle *GM* at household level for aggregation at different levels. The computed *GM* could be mapped by assigning it to the mapped cattle population in a given production system or for the country as a whole. This approach allows us to assess the geographic magnitude and distribution of the benefits of intervention and to match their level of interventions and expenditures to potential benefits (Thornton and Herrero 2014).

Ex-ante impact assessment

Financial profitability

The financial feasibility of cattle policy and investment interventions is analysed using a multi-year partial budgeting framework. The partial budgeting implies that only the costs and benefits which differ between the 'with' and the 'without' policy and investment interventions had to be considered. Therefore, the net incremental cash flow (given as the difference between incremental benefits and incremental costs) from the policy and investment interventions over a given planning time horizon (T) is derived and analysed using three principal financial measures: (1) net present value (*NPV*), (2) benefit cost ratio (*BCR*), and (3) internal rate of return (*IRR*).

Thus, the net incremental cash flow (CF_t) due to the policy and investment interventions at time *t* is mathematically given as:

$$CF_t = (B_t^w - B_t^{WO}) - (C_t^W - C_t^{WO}) \tag{20}$$

where B_t^w and B_t^{wo} are monetary benefits of the 'with' and 'without' interventions, respectively and C_t^w and C_t^{wo} are the costs for the 'with' and 'without' interventions, respectively. Then, the present value *(PV)* of net incremental cash flows from the policy and investment interventions over a T-year planning time horizon is given as:

$$NPV_O = -I_0 + \sum_{t=1}^{T} \frac{(B_t^w - B_t^{WO}) - (C_t^W - C_t^{WO})}{(1+\delta)^t} = -I_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+\delta)^t} \tag{21}$$

where δ is the discount rate (assumed to be 10%); I_0 is the initial investment cost to be realized over the period t=0; and the other variables are defined as before. The *NPV* provides a basis on which to determine whether the return on a project will be positive or negative and with which to compare different potential projects. As a rule, projects with positive *NPV*s are accepted.

The annualized present value of incremental net benefit (*ANPV*) from 'with' policy and investment intervention for a given herd class in a given production system is given as follows:

$$ANPV = PV * \frac{\delta * (1+\delta)^t}{(1+\delta)^t - 1} \tag{22}$$

Where PV is the present value of the net incremental cash flow and the other variables are as defined as before. The productivity impact of the intervention is also assessed in terms of the annual incremental net benefit generated per individual cattle and incremental net per capita income.

In addition, the benefit cost ratios (BCR_s) and the internal rate of returns (IRR_s) are also calculated for the incremental benefits and incremental costs of the interventions. The BCR measures the total financial return for each unit of money invested in cattle production and provides a measure of the efficiency with which the limited funds are utilized to generate the realized benefits. The BCR criterion measures the effectiveness of investment and is very important in a situation where several projects are competing for the same limited funds. Based on the BCR investment criterion, it is advisable to invest if the BCR is greater than 1 and the priority is given to the project with the higher or highest BCR. The BCR is given by the following formula:

$$BCR = \sum_{t=0}^{T} \frac{(B_t^W - B_t^{WO})}{(1+\delta)^t} / \sum_{t=0}^{T} \frac{(C_t^W - C_t^{WO})}{(1+\delta)^t} + I_0 \tag{23}$$

Finally, the IRR of the net incremental cash flow for the 'with' intervention situation is obtained. The IRR is a discount rate that, when applied to the future streams of project costs and benefits, produces a NPV of zero. It expresses the return to the investment in the project as an interest rate. It, therefore, permits the comparison of the return to the investment in the current project with the return to the investment in other possible projects or to simply investing the funds in an interest-earning bank account. Then, in order to make an investment decision, the value of IRR is compared with the cost of capital. For example, the value of IRR greater than the current lending rate indicates that the investment is profitable. In other words, the investment must satisfy the condition that IRR is greater than δ to justify the initial investment interventions. This indicates that the degree to which the return to a livestock investment intervention is comparable to the return to alternative investment options elsewhere and hence competes for available funds. Mathematically, the IRR is expressed as:

$$-I_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+IRR)^t} = 0 \tag{24}$$

where CF_t is the net incremental cash flow at time *t* and *IRR* is the internal rate of return. The idea is to solve equation (24) for the *IRR*.

Future production–consumption balances

The impact of policy and investment interventions in cattle production is also assessed in terms of the extent to which it contributes towards closing the growing future production–consumption gaps for beef and cow milk in Ethiopia. The computation of current and projected beef and cow milk production is made using a deterministic 20 year herd growth model as discussed in section 3. On the other hand, the computation of current and projected beef and cow milk consumption requirements is made using the information on income elasticity of demand for beef and cow milk, growth in real per capita GDP and human population. Thus, the projected per capita consumption of beef (or milk) is given as:

$$C_t = C_0 * (1 + \eta * \gamma)^t \tag{25}$$

Where C_t is the projected per capita beef (or milk) consumption for a given year t; C_0 is a baseline per capita consumption of beef (or milk); η is the income elasticity of demand for beef (or milk); and γ is the trend annual growth rate of real per capita *GDP*. Then, the projected total consumption of beef (or milk) for future time period t (TC_t) is obtained by multiplying the projected per capita consumption with the projected population (POP_t) for that given period of time:

$$TC_t = C_0 * (1 + \eta * \gamma)^t * POP_t = C_t * POP_t \tag{26}$$

In this projection, the human population projection is based on the CSA population projection for medium variant population growth scenario for Ethiopia. Thus, the annual trend growth rate for real per capita GDP is obtained by taking the difference between the average GDP and population growth rates over the last seven years (2007–2013). The income elasticity estimates used in the projections of meat and milk consumption are based on estimates, by International Food Policy Research Institute, derived from household income, consumption and expenditure survey data for 2004/05 (Tafere et al. 2012). The income elasticity estimate for beef and dairy products (including milk) is 0.939 and 0.420, respectively (Tafere et al. 2012).

5. Results and discussions

5.1 Results of baseline assessments

Agro-pastoral and pastoral production systems

Parameterization of the cattle herd growth model

Baseline cattle herd size and structure

In the LG system, three representative cattle production systems are considered: agro-pastoral, pastoral small herd size and pastoral medium herd size. The baseline cattle herd size and structure for agro-pastoral and pastoral production systems used in calibrating the cattle herd projection matrices is given in Table 1. The average cattle herd size for agro-pastoral systems is 9, while the average cattle herd size for small and medium herd size pastoral system is 7 and 18 heads of cattle, respectively. The structure of cattle herd is analysed at two levels: globally and by sex. Globally (combining all sexes and stages of cattle growth), the cattle herd in both agro-pastoral and pastoral production systems are dominated by female cattle. The female cattle in agro-pastoral herd accounts for 59%, while the male account for about 41% of the cattle herd. The proportion of female in the cattle herd is even higher for pastoral herd. For example, the proportion of female cattle in the pastoral small-sized herd is 68%, while in the case of pastoral medium-sized herd the proportion of female cattle is 70%. In general, cattle growth stage-wise in the adult cattle are dominant, while sex-wise the female cattle are dominant in the cattle herd for agro-pastoral and pastoral production systems. The structure of cattle herd clearly indicates the focus of agro-pastoralists and pastoralists on cattle reproduction and milk production. It is also important to see that they keep significant proportion of adult males which could be removed earlier as sub-adult after keeping enough breeding bulls.

Table 1. Baseline initial cattle herd size and structure for agro-pastoral and pastoral cattle production systems

Stage class	Agro-pastoral			Pastoral-small herd size			Pastoral-medium herd size		
	Herd size	Structure		Herd size	Structure		Herd size	Structure	
		Global	Intra-sex		Global	Intra-sex		Global	Intra-sex
Young female (Fj)	0.81	0.09	0.15	0.98	0.14	0.21	2.52	0.14	0.20
Sub-adult female (Fs)	1.08	0.12	0.20	0.42	0.06	0.09	1.98	0.11	0.16
Adult female (Fa)	3.42	0.38	0.64	3.36	0.48	0.71	8.10	0.45	0.64
Young male (Mj)	0.90	0.10	0.24	0.42	0.06	0.20	1.44	0.08	0.27
Sub-adult male (Ms)	0.63	0.07	0.17	0.28	0.04	0.13	1.26	0.07	0.23
Adult male (Ma)	2.16	0.24	0.59	1.4	0.20	0.67	2.70	0.15	0.50
Total	9			7			18.00		

Source: Simulation results

Cattle herd demographic rates

The detailed initial stage-specific demographic rates used in calibrating the cattle herd projection matrices for agro-pastoral and pastoral production systems are given in Table 2. The cattle demographic rates varied by sex, stage of growth and production systems. The data on demographic rates include: class age range in years, stage duration in years, annual mortality rates, annual survival rate and annual fecundity rates. It is important to note that the observed mortality rates are higher for male cattle as compared to female cattle and for younger cattle as compared to older or mature cattle. Due to lack of data similar levels of commercial offtake rates are assumed for both agro-pastoral and pastoral production systems. The initial assumed annual survival rate is also similar across different production systems because of the assumed similar levels of annual mortality and annual commercial offtake rates. The observed annual fecundity rate among the reproductive adult female cows is considered very low and estimated at about 50–52%.

Table 2. Initial stage specific demographic rates used in calibrating cattle herd projection matrices for agro-pastoral and pastoral cattle production systems

Stage class	Class age range in years	Stage duration in years (di)	Annual mortality rate (mi)	Annual offtake rate (oi)	Annual survivorship rate (si)	Annual fecundity rate (F)
Agro-pastoral						
Fj	0–1	1	0.14	0.00	0.86	0.00
Fs	1–3.5	2.5	0.06	0.02	0.92	0.00
Fa	3.5–11	7.5	0.04	0.06	0.90	0.51
M	0–1	1	0.15	0.06	0.79	0.00
Ms	1–3.5	2.5	0.09	0.03	0.88	0.00
Ma	3.5–9.5	6	0.07	0.30	0.63	0.00
Pastoral-small herd size						
Fj	0–1	1	0.12	0.00	0.88	0.00
Fs	1–3.5	2.5	0.07	0.02	0.91	0.00
Fa	3.5–11	7.5	0.05	0.05	0.90	0.50
Mj	0–1	1	0.16	0.06	0.78	0.00
Ms	1–3.5	2.5	0.12	0.10	0.78	0.00
Ma	3.5–9.5	6	0.09	0.20	0.71	0.00
Pastoral-medium herd size						
Fj	0–1	1	0.10	0.00	0.90	0.00
Fs	1–3	2	0.06	0.02	0.92	0.00
Fa	3–10.5	7.5	0.05	0.06	0.89	0.52
Mj	0–1	1	0.16	0.12	0.72	0.00
Ms	1–3	2	0.12	0.10	0.78	0.00
Ma	3–8	5	0.09	0.15	0.76	0.00

Source: Simulation results

Stage-structured population projection matrices

The annual Lefkovitch stage-structured population projection matrices for agro-pastoral and pastoral cattle herds are given in Table 3. The population projection matrices are derived using the demographic rates given in Table 2. The matrix is applied to initial cattle herd to provide cattle herd growth dynamics over time. The parameters of population projection matrix determines whether the cattle herd is declining, held constant or growing over time. The parameters also reflect the state of cattle productivity development and are affected by the changes in policy and investment interventions.

Table 3. Annual Lefkovitch stage-structured population projection matrices for cattle herd in agro-pastoral and pastoral cattle production systems

Stage at year t+1	Stage at year t					
	Fj	Fs	Fa	Mj	Ms	Ma
Agro-pastoral						
Fj	0.00	0.00	0.25	0.00	0.00	0.00
Fs	0.86	0.48	0.00	0.00	0.00	0.00
Fa	0.00	0.34	0.90	0.00	0.00	0.00
Mj	0.00	0.00	0.25	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.79	0.56	0.00
Ma	0.00	0.00	0.00	0.00	0.32	0.63
Pastoral–small herd size						
Fj	0.00	0.00	0.25	0.00	0.00	0.00
Fs	0.88	0.57	0.00	0.00	0.00	0.00
Fa	0.00	0.34	0.90	0.00	0.00	0.00
Mj	0.00	0.00	0.25	0.00	0.00	0.00

Stage at year t+1	Stage at year t					
	Fj	Fs	Fa	Mj	Ms	Ma
Ma	0.00	0.00	0.00	0.00	0.26	0.71
Pastoral–medium herd size						
Fj	0.00	0.00	0.26	0.00	0.00	0.00
Fs	0.90	0.48	0.00	0.00	0.00	0.00
Fa	0.00	0.44	0.89	0.00	0.00	0.00
Mj	0.00	0.00	0.26	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.72	0.56	0.00
Ma	0.00	0.00	0.00	0.00	0.32	0.76

Source: Simulation results

Simulation of baseline cattle herd growth dynamics

Cattle herd growth rates, stable stage distributions and stage-specific reproductive values

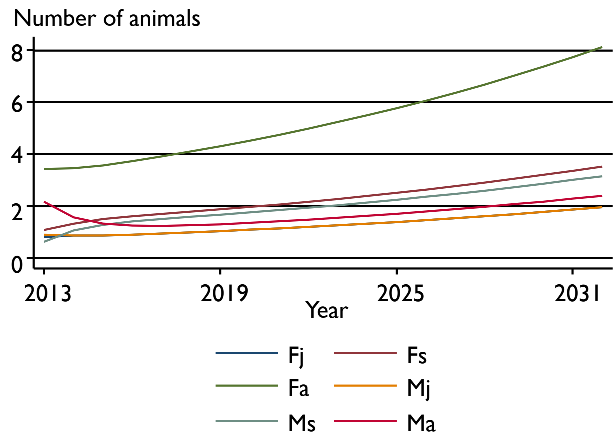
The baseline stable stage distribution, stage-specific reproductive values and annual long-term cattle population multiplication rates for agro-pastoral and pastoral production systems are given in Table 4. The projected number of cattle by different classes of cattle for agro-pastoral production systems are given in Figures 1, 2 and 3. There is upward trend in the number of cattle for all cattle types especially noticeable for female adult cattle. Under the baseline scenario, the long-run cattle multiplication rate for agro-pastoral production system is 1.05 which implies a 5% cattle growth rate per year. The stable stage distribution associated with this constant cattle growth rate is 9%, 17%, 38%, 9%, 15%, and 11% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male cattle, respectively. The stable stage distribution is also dominated by female cattle especially adult females. As compared to the initial cattle herd structure, the stable herd growth results in a lower proportion of sub-adult female and a substantially higher proportion of adult male cattle. It also observed that the adult female contributes most to the cattle reproduction followed by sub-adult female. The reproductive value of male cattle is assumed to be zero in this kind of cattle growth modelling.

Table 4. Baseline stable stage distribution (w), stage-specific reproductive values (v) and annual long-term population multiplication rate for agro-pastoral and pastoral cattle production systems

Sex-stage class	Agro-pastoral		Pastoral–small herd size		Pastoral–medium herd size	
	w	V	w	v	w	V
Fj	0.09	1.00	0.09	1.00	0.10	1.00
Fs	0.17	1.22	0.17	1.19	0.15	1.17
Fa	0.38	1.68	0.39	1.68	0.40	1.54
Mj	0.09	0.00	0.09	0.00	0.10	0.00
Ms	0.15	0.00	0.14	0.00	0.11	0.00
Ma	0.11	0.00	0.10	0.00	0.13	0.00
λ	1.05		1.05		1.06	

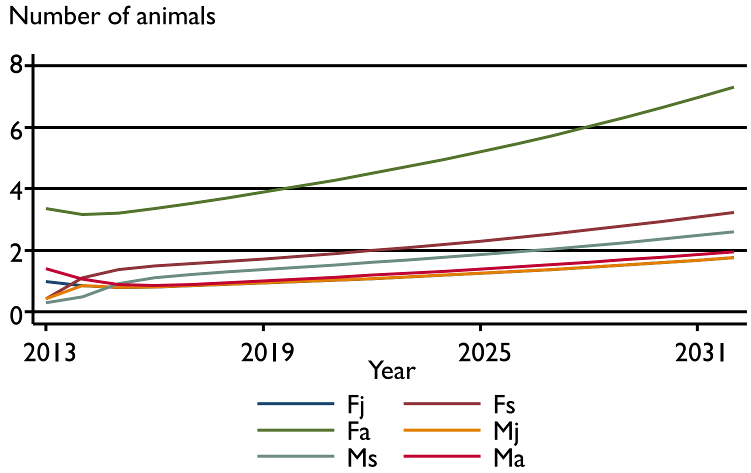
Source: Simulation results

Figure 1: Number of cattle by sex and stage of growth, agro-pastoral herd



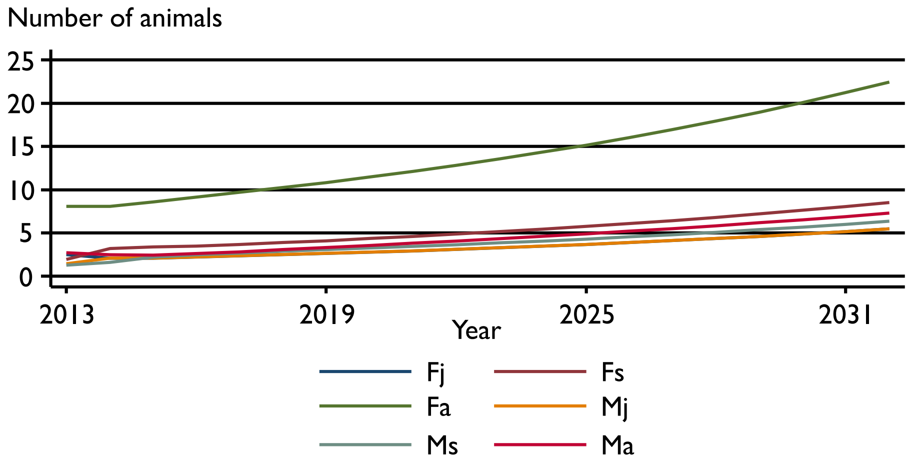
Source: Simulation results

Figure 2: Number of cattle by sex and stage of growth, pastoral small herd



Source: Simulation results.

Figure 3: Number of cattle by sex and stage of growth, pastoral medium herd



Source: Simulation results.

Similar stable stage distribution and stage-specific reproductive values are observed for both small- and medium-sized herd pastoral production systems. Under the baseline scenario, the long-run multiplication rate for pastoral small and medium-sized herd cattle is 1.05 and 1.06, respectively which correspond to a 5% and 6% annual growth rate, respectively. The stable stage distribution associated with a 4% annual growth rate for pastoral small-sized cattle herd is 9%, 17%, 39%, 9%,14% and 10% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male cattle, respectively. On the other hand, the stable stage distribution associated with a 6% annual growth rate for pastoral medium-sized pastoral cattle herd is 10%, 15%, 40%, 10%,11% and 13% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male cattle, respectively

Sensitivity and elasticity analysis

The results of sensitivity and elasticity analyses for agro-pastoral and pastoral production systems are given in Table 5. The sensitivity and elasticity analyses provide a measure which indicate the degree to which changes in demographic rates in the projection matrix result in a change in the population trend (Caswell 1989). The results of elasticity analysis shows that the long-term cattle population growth rate in agro-pastoral and pastoral herd is most elastic to the probability that an adult female survives and persists as an adult. The adult female survival contributes about 60% to the cattle herd growth trend. The annual population growth rate is the second most elastic to the survival probability of sub-adult female cattle. Specifically, a 1% increase in sub-adult survival rate results in about 20–22% increase in annual multiplication rate. In terms of stages of growth, it is also interesting to note that young female cattle, sub-adult and adult stage contribute 10–11%, 19–21%, and 70%, respectively, to cattle herd growth. Furthermore, it is also important to note that the female cattle fertility contributes only about 10–11%, while the annual survival rate contributes about 89–90% to the cattle growth rate. In general, the baseline scenario analyses indicate that it is more important to reduce the mortality rate than improving the fertility of cattle to increase cattle growth in agro-pastoral and pastoral production systems. This indicates the importance of identifying the causes of cattle mortality and implementing cost-effective measures to reduce it. However, it should be also noted that since there is low level of cattle productivity, improving the fertility of cattle is also important.

Table 5. Sensitivity and elasticity matrices from Lefkovitch stage-structured population projection matrix for agro-pastoral and pastoral cattle production systems

	Sensitivity matrix			Elasticity matrix			
	Fj	Fs	Fa	Fj	Fs	Fa	Total
Agro-pastoral							
Fj	0.00	0.00	0.41	0.00	0.00	0.10	0.10
Fs	0.12	0.22	0.00	0.09	0.12	0.00	0.21
Fa	0.00	0.30	0.68	0.00	0.10	0.59	0.70
Total				0.10	0.22	0.69	
Pastoral–small herd size							
Fj	0.00	0.00	0.41	0.00	0.00	0.10	0.10
Fs	0.12	0.21	0.00	0.09	0.12	0.00	0.21
Fa	0.00	0.30	0.69	0.00	0.10	0.59	0.70
Total				0.09	0.22	0.69	
Pastoral–medium herd size							
Fj	0.00	0.00	0.45	0.00	0.00	0.11	0.11
Fs	0.12	0.20	0.00	0.11	0.09	0.00	0.19
Fa	0.00	0.26	0.690	0.00	0.11	0.58	0.70
Total				0.11	0.20	0.69	

Source: Simulation results.

Simulation of steady state cattle herd growth dynamics

Stable stage distributions, stage-specific reproductive values and commercial offtake rates

The steady-state stage distribution, stage-specific reproductive values and commercial offtake rates for agro-pastoral and pastoral production systems are given in Table 6. Under steady state the cattle growth rate is assumed to be zero in that the cattle herd size is kept constant at the initial level. So the expected changes are in terms of stable stage distribution and offtake rates as compared to the initial cattle herd structure.

Table 6. Steady-state stable stage distribution (w), stage specific reproductive values (v) and offtake rates for agro-pastoral and pastoral production systems

Stage class	Agro-pastoral			Pastoral-small herd size			Pastoral-medium herd size		
	w	v	Offtake rate	w	V	Offtake rate	W	V	Offtake rate
Fj	0.08	1.00	0.00	0.09	1.00	0.00	0.09	1.00	0.00
Fs	0.17	1.16	0.02	0.18	1.14	0.02	0.16	1.11	0.02
Fa	0.37	1.44	0.12	0.37	1.45	0.11	0.38	1.32	0.13
Mj	0.08	0.00	0.06	0.09	0.00	0.06	0.09	0.00	0.12
Ms	0.15	0.00	0.03	0.14	0.00	0.10	0.12	0.00	0.10
Ma	0.13	0.00	0.30	0.12	0.00	0.20	0.16	0.00	0.15

Source: Simulation results.

The steady state cattle production is obtained by numerically adjusting the offtake rates by sex and stage of cattle growth. It is to be recalled that in agro-pastoral and pastoral the cattle population is growing under the baseline scenario and, therefore, in order to obtain steady state cattle production there is a need to decrease the cattle herd size by decreasing the cattle types (sex and stage) which significantly contribute to cattle growth. Thus, the zero cattle growth rate is obtained by increasing the commercial offtake of female cattle, mainly sub-adult and adult female cattle. As a result, under the steady state the percentage of sub-adult female cattle offtake has increased as compared to the baseline scenario. For example, in the case of agro-pastoral and pastoral herd, the commercial offtake rates for adult female cattle increased from 6% and 5% in the baseline situation to 12% and 11%, respectively. The male offtake rates remained constant as males do not contribute to long-term cattle growth. In general, the observed baseline offtake rate is below the steady state offtake rate which indicates suboptimal offtake strategy practiced by livestock keepers and the need to investigate the reason for this practice.

Beef and milk production

The annual steady state beef production (total carcass weight in kg) by different cattle production systems is given in Table 7. The average annual offtake rate for the cattle herd from agro-pastoral and pastoral production systems is the same and 9%. This offtake rate is very low especially given the fact that cattle are not used for draft power in pastoral production systems. For the agro-pastoral cattle herd the average annual beef production per cattle herd is 87 kg. The annual average beef offtake of 74 kg/herd and 211 kg/herd is obtained for the small- and medium-sized pastoral production system, respectively. In the case of milk, the average annual milk offtake for agro-pastoral, small and medium-sized pastoral herd is 425 litre/herd, 386 litre/herd, 1277 litre/herd, respectively.

Table 7. Steady state beef and milk production and annualized present value of gross margins for agro-pastoral and pastoral cattle production systems in Ethiopia[1]

Production system	Average net offtake rate (%)	Average annual beef production from the herd (kg/herd)[2]	Average annual milk production (litre/herd)	Annualized present value per cattle herd (ETB)	Annualized present value per head of cattle (ETB/head)
Agro-pastoral	0.09	87	425.0	62,672	6963
Pastoral small herd size	0.09	74	386.0	26,504	3786
Pastoral medium herd size	0.09	211	1277.0	147,310	8184

Note: [1]The time horizon for the projection is 28 years. [2]The annual beef production is in carcass weight equivalent assuming 45 to 50% dressing percentage.
Source: Simulation results.

Financial profitability

The results of the analysis of financial probability of beef production from extensive agro-pastoral and pastoral production systems at steady state is given in Table 7. The annualized present values of *GM* for cattle outputs per herd and head of cattle are given in Table 7. The annualized present value of *GM* per cattle herd for agro-pastoral and pastoral small herd and medium herd size is ETB62,672, ETB26,504 and ETB147,310, respectively. The annualized present value of cattle output per head of cattle is also computed and found to be ETB6963 for agro-pastoral herd, while for the small and medium-sized pastoral herd the annualized present value of gross margin per head of cattle is ETB3786 and ETB8184, respectively. Thus, the agro-pastoral system is more productive than the small herd size pasture livestock production system.

MRD crop–livestock production system

Parameterization of cattle herd growth model

Baseline cattle herd size and structure

For the MRD system, two representative cattle production systems are considered: small- and medium-sized herd MRD. The baseline or initial cattle herd size and structure for the MRD production system used in calibrating the cattle herd projection matrices is given in Table 8. In general, the observed cattle herd sizes are very small for the MRD. The average cattle herd size for small herd MRD is two, while the average cattle herd size for the medium MRD is six heads of cattle. The structure of cattle herd is analysed at two levels: globally and by sex. The female cattle in small herd size accounts for 56%, while the male account for about 44%, of the cattle herd. In the case of medium herd, the proportion of female cattle herd is 54%. Similar to the agro-pastoral and pastoral production system, the female adult cattle are dominant classes of cattle for the MRD production system. Furthermore, the adult classes are the dominant classes of cattle accounting for more than 65% of the cattle herd in both systems. This structure indicates the importance of cattle reproduction (replacement of oxen and cows) and for draft power and milk production.

Table 8. Baseline initial cattle herd size and structure for the MRD cattle production system

Stage class	Small herd size			Medium herd size		
	Herd size	Structure		Herd size	Structure	
		Global	Intra-sex		Global	Intra-sex
Fj	0.14	0.07	0.13	0.54	0.09	0.17
Fs	0.20	0.10	0.18	0.54	0.09	0.17
Fa	0.78	0.39	0.70	2.16	0.36	0.67
Mj	0.16	0.08	0.18	0.48	0.08	0.17
Ms	0.18	0.09	0.20	0.48	0.08	0.17
Ma	0.54	0.27	0.61	1.86	0.31	0.66
Total	2.00			6.00		

Source: Simulation results.

Cattle herd demographic rates

The detailed initial stage-specific demographic rates used in calibrating cattle herd projection matrices for the MRD production system are given in Table 9. The cattle demographic rates varied by sex, stage of growth and production systems. It is interesting to note that the observed mortality rates are higher for younger cattle as compared to older or mature cattle. Due to the lack of data, similar levels of commercial offtake rates are assumed for all MRD production systems. The initial assumed annual survival rate is also similar across different production systems because of the assumed similar levels of annual mortality rates and annual offtake rates. The observed annual fecundity rate among the reproductive female cows is considered to be very low and estimated at about 51% and 52% for small herd and medium herd, respectively.

Table 9. Stage specific demographic rates used in calibrating cattle herd projection matrices for the MRD cattle production system

Stage class	Class age range in years	Stage duration in years (di)	Annual mortality rate (mi)	Annual offtake rate (oi)	Annual survivorship rate (si)	Annual fecundity (F)
Small herd size						
Fj	0–1	1	0.11	0.00	0.89	0.00
Fs	1–3	2	0.07	0.05	0.88	0.00
Fa	3–11	8	0.05	0.07	0.88	0.51
Mj	0–1	1	0.12	0.05	0.83	0.00
Ms	1–3	2	0.08	0.15	0.77	0.00
Ma	3–9	6	0.05	0.05	0.90	0.00
Medium herd size						
Fj	0–1	1	0.12	0.00	0.88	0.00
Fs	1–3	2	0.07	0.05	0.88	0.00
Fa	3–11	8	0.05	0.05	0.90	0.52
Mj	0–1	1	0.16	0.05	0.79	0.00
Ms	1–3	2	0.08	0.15	0.77	0.00
Ma	3–9	6	0.06	0.07	0.87	0.00

Source: Simulation results.

Stage-structured population projection matrices

The annual Lefkovitch stage-structured population projection matrices for agro-pastoral and pastoral cattle herds are given in Table 10. The population projection matrices are derived using the demographic rates given in Table 9. The matrix is applied to initial cattle herd to provide cattle herd growth dynamics over time. The parameters of population projection matrix determines whether the cattle herd is declining, held constant or growing over time. The parameters also reflect the state of cattle productivity development in MRD production systems and are affected by the changes in policy and investment interventions.

Table 10. Annual Lefkovitch stage-structured population projection matrices for cattle herd in the MRD cattle production system

Stage at year t+1	Stage at year t					
	Fj	Fs	Fa	Mj	Ms	Ma
Small herd size						
Fj	0.00	0.00	0.26	0.00	0.00	0.00
Fs	0.89	0.47	0.00	0.00	0.00	0.00
Fa	0.00	0.41	0.88	0.00	0.00	0.00
Mj	0.00	0.00	0.25	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.83	0.43	0.00
Ma	0.00	0.00	0.00	0.00	0.33	0.90
Medium herd size						
Fj	0.00	0.00	0.26	0.00	0.00	0.00
Fs	0.88	0.47	0.00	0.00	0.00	0.00
Fa	0.00	0.41	0.90	0.00	0.00	0.00
Mj	0.00	0.00	0.26	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.79	0.43	0.00
Ma	0.00	0.00	0.00	0.00	0.33	0.87

Source: Simulation results.

Simulation of baseline cattle herd growth dynamics

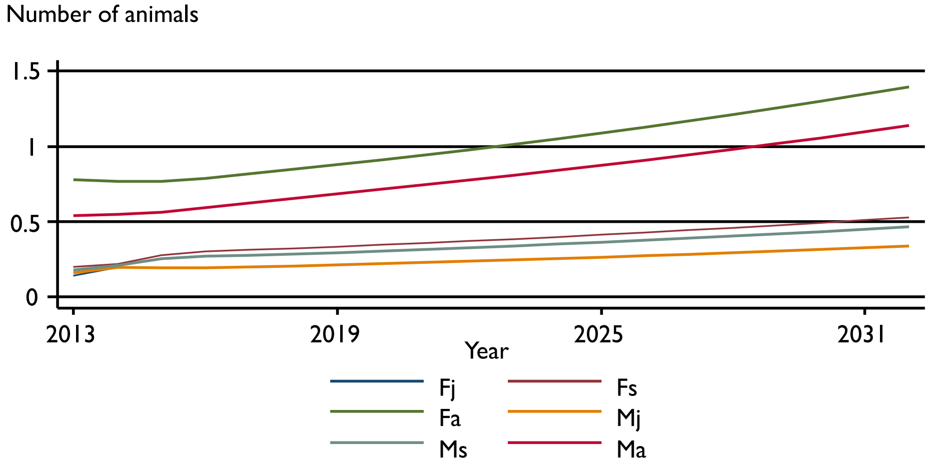
Cattle herd growth rates, stable stage distributions and stage-specific reproductive values

The baseline stable stage distribution, stage-specific reproductive values and annual long-term cattle population multiplication rates for the MRD production system are given in Table 11. The projection of the number of animals for different classes of cattle for small herd and medium herd are given in Figure 4 and Figure 5, respectively. In general, there is upward trend in number of animals for all cattle types. It is observed that under the baseline scenario, the long-run cattle multiplication rate for the MRD production system is 1.04 which implies a 4% annual growth rate in cattle herd.

Table 11. Baseline stable stage distribution (w), stage specific reproductive values (v) and annual long-term population multiplication rate and per capita growth rate for the MRD cattle production system

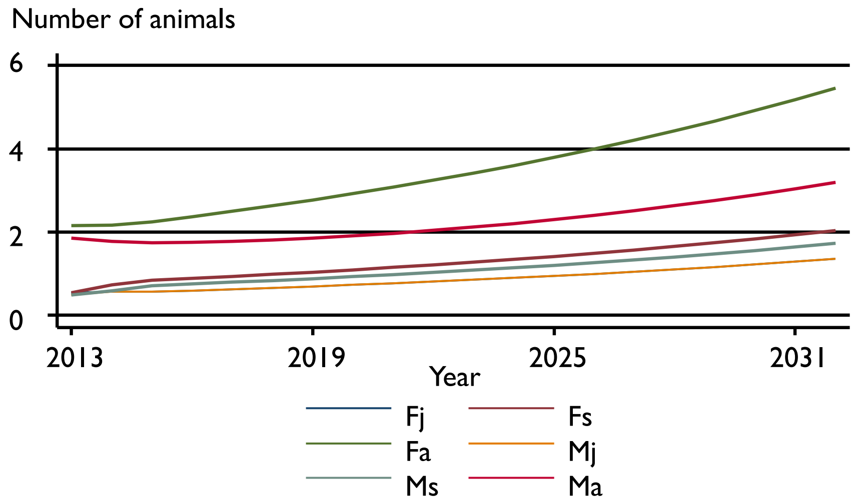
Stage class	Small herd size		Medium herd size	
	w	V	w	V
Fj	0.08	1.00	0.09	1.00
Fs	0.12	1.16	0.13	1.20
Fa	0.33	1.61	0.36	1.70
Mj	0.08	0.00	0.09	0.00
Ms	0.11	0.00	0.11	0.00
Ma	0.27	0.00	0.21	0.00
λ	1.04		1.05	

Figure 4: Number of cattle by sex and stage of growth, MRD small herd



Source: Simulation results.

Figure 5: Number of cattle by sex and stage of growth, MRD medium herd



Source: Simulation results.

In the case of small-sized cattle herd, the stable stage distribution associated with this constant cattle growth rate is 8%, 12%, 33%, 8%, 11%, and 27% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male cattle, respectively. Similar to initial stage structure, the stable stage distribution is also dominated by female cattle especially adult females. It is also observed that the adult females contribute most to the cattle reproduction followed by sub-adult females. Similar stable stage distribution and stage-specific reproductive values are observed for medium-sized herd MRD production systems.

Sensitivity and elasticity analysis

The results of sensitivity and elasticity analyses for the MRD production system are given in Table 12. Similar to agro-pastoral and pastoral production systems, the elasticity analysis shows that the long-term cattle population growth rate is most elastic to the probability that an adult female survives and persists as an adult. The adult female survival contributes about 61% to the cattle herd growth. The annual population growth rate is second most elastic to the probability that sub-adult female survives and stays as a sub-adult. Specifically, a 1% increase in sub-adult survivorship results in about 18% increase in annual multiplication rate. In terms of stages of growth, it is also interesting to note that young female cattle, sub-adult and adult stage contribute 10%, 19%, and 71%, respectively, to cattle herd growth.

Furthermore, it is also important to note that the female cattle fertility contributes only 10%, while the annual survival rate contributes about 89% to the cattle herd growth rate. Thus, under the baseline scenario, it is more important to reduce mortality rate than improving the fertility rate of cattle in order to increase cattle growth in MRD production systems.

Table 12. Sensitivity and elasticity matrices from Lefkovitch stage-structured population projection matrix for the MRD cattle production system

	Sensitivity matrix			Elasticity matrix			
	Fj	Fs	Fa	Fj	Fs	Fa	Total
Small herd size							
Fj	0.00	0.00	0.44	0.00	0.00	0.10	0.10
Fs	0.12	0.19	0.00	0.10	0.09	0.00	0.19
Fa	0.00	0.27	0.70	0.00	0.10	0.61	0.71
Total				0.10	0.19	0.71	
Medium herd size							
Fj	0.00	0.00	0.42	0.00	0.00	0.10	0.10
Fs	0.12	0.19	0.00	0.10	0.09	0.00	0.19
Fa	0.00	0.26	0.71	0.00	0.10	0.61	0.71
Total				0.10	0.19	0.71	

Source: Simulation results.

Simulation of steady state cattle herd growth dynamics

Stable stage distributions, stage-specific reproductive values and commercial offtake rates

The steady-state stage distribution, stage-specific reproductive values and offtake rates for the MRD production system are given in Table 13. The steady state cattle production is obtained by numerically adjusting the commercial offtake rates by sex and stage of cattle growth. It is to be recalled that the cattle population in MRD production systems is growing under the baseline scenario and, therefore, in order to obtain steady state cattle production there is a need to decrease the cattle herd size by decreasing the cattle classes (sex and stage) which significantly contribute to cattle growth. Thus, the zero cattle growth rate characterizing the steady state is obtained by changing the commercial offtake of female cattle mainly sub-adult and adult female cattle. In the case of small herd MRD, the offtake rate for sub-adult female cattle remained the same, while for adult female the steady state offtake rate decreased slightly. On the other hand, the steady state offtake rates for both sub-adult and adult female cattle increased in the case of medium-sized herd for the MRD production system.

Table 13. Steady-state stable stage distribution (w), stage specific reproductive values (v) and offtake rates for the MRD cattle production system

Stage class	Small herd size			Medium herd size		
	w	v	Offtake rate	W	v	Offtake rate
Fj	0.08	1.00	0.00	0.10	1.00	0.00
Fs	0.14	1.12	0.04	0.16	1.14	0.08
Fa	0.36	1.42	0.03	0.39	1.56	0.11
Mj	0.08	0.00	0.05	0.10	0.00	0.10
Ms	0.12	0.00	0.15	0.12	0.00	0.20
Ma	0.20	0.00	0.05	0.14	0.00	0.21

Source: Simulation results.

Beef and milk production

The annual steady state beef production (total carcass weight) by different cattle production system is given in Table 14. The average annual offtake rate for the small herd size cattle is 5%, while for medium herd size cattle the average annual net offtake rate is 12%. For small cattle herd the average annual beef production per cattle herd is 10 kg, while it is 66 kg/herd for medium-sized cattle herd. The average annual milk production for the small-sized cattle herd is 108 litres/herd, while for medium-sized cattle herd the average annual milk production is 335 litres/herd.

Table 14. Steady state beef and milk production and annualized present value of gross margins by different cattle production systems in Ethiopia[1]

Production system	Average net offtake rate (%)	Average annual beef production from the herd (Kg)[2]	Average annual milk production (Litre)	Annualized present value per cattle herd (ETB)	Annualized present value per head of cattle (ETB/head)
MRD					
Small herd size	5	10	108.0	14620	7310
Medium herd size	12	66	335.0	43370	7228

Note: [1]The time horizon for the projection is 28 years. [2]The annual beef production is in carcass weight equivalent assuming 45% to 50% dressing percentage.
Source: Simulation results.

Financial profitability

The results of the analysis of financial probability of beef production at steady state cattle production is given in Table 14. The annualized present value of *GM* for beef production per head of cattle is also given in Table 14. The annualized present value of cattle output per head for cattle for small herd size MRD is estimated to be ETB7310. In the case of medium-sized herd MRD, the annualized present value of *GM* for cattle outputs per head of cattle is ETB7228. Similar levels of productivity are observed for small and medium herd size cattle herds.

MRS crop–livestock production system

Parameterization of cattle herd growth model

Baseline cattle herd size and structure

The baseline initial cattle herd size and structure for the MRS production system used in calibrating the cattle herd projection matrices is given in Table 15. The observed cattle herd sizes are relatively higher than that of the MRD but lower than the agro-pastoral and pastoral production systems. The average cattle herd size for small herd size MRS is three, while the average cattle herd size for medium MRD is nine heads of cattle. The female cattle in small herd size accounts for 54%, while the male account for about 46% of the cattle herd. The proportion of female in the medium herd is found to be 52%. Similar to other cattle production systems, stage-wise the adult cattle are dominant while sex-wise the female cattle are dominant in the cattle herd for the MRS production system. However, the level of female cattle dominance is lower for the MRS as compared to other cattle production systems. This might be due to a greater draft power requirement for crop production.

Table 15. Baseline initial cattle herd size and structure for the MRS cattle production system

Stage class	Small herd size			Medium herd size		
	Herd size	Structure		Herd size	Global	Intra-sex
		Global	Intra-sex			
Fj	0.24	0.08	0.15	0.81	0.09	0.17
Fs	0.27	0.09	0.17	0.72	0.08	0.15
Fa	1.11	0.37	0.69	3.15	0.35	0.67
Mj	0.21	0.07	0.16	0.72	0.08	0.17
Ms	0.18	0.06	0.13	0.72	0.08	0.17
Ma	0.96	0.32	0.71	2.79	0.31	0.66
Total	3			9.00		

Source: Simulation results.

Cattle herd demographic rates

The detailed initial sage-specific demographic rates used in calibrating cattle herd projection matrices for the MRS production system are given in Table 16. The cattle demographic rates varied by sex, stage of growth and herd size. The level of stage-specific demographic rates assumed in MRS in calibrating the cattle herd projection matrices is similar to the other cattle production systems. In general, it is observed that mortality rates are higher for male cattle as compared to female cattle and for younger cattle as compared to older or mature cattle. The observed annual fecundity rate among the reproductive female cows is considered very low and estimated at about 55% and 59% for the small-sized herd and medium-sized herd, respectively.

Table 16. Stage specific demographic rates used in calibrating cattle herd projection matrices for the MRS cattle production system

Stage class	Class age range in year	Stage duration in year (di)	Annual mortality rate (mi)	Annual offtake rate (oi)	Annual survivorship rate (si)	Annual fecundity rate (F)
Small herd size						
Fj	0–1	1	0.12	0.00	0.88	0.00
Fs	1–3	2	0.07	0.05	0.88	0.00
Fa	3–11	8	0.04	0.05	0.91	0.55
Mj	0–1	1	0.15	0. 05	0.80	0.00
Ms	1–3	2	0.08	0.15	0.77	0.00
Ma	3–9	6	0.04	0.05	0.91	0.00
Medium herd size						
Fj	0–1	1	0.08	0.00	0.92	0.00
Fs	1–2.5	1.5	0.06	0.05	0.89	0.00
Fa	2.5–10.5	8	0.04	0.05	0.91	0.59
Mj	0–1	1	0.10	0.05	0.85	0.00
Ms	1–2.5	1.5	0.06	0.10	0.84	0.00
Ma	2.5–10.5	8	0.04	0.05	0.91	0.00

Source: Simulation results.

Stage-structured population projection matrices

The annual Lefkovitch stage-structured population projection matrices for agro-pastoral and pastoral cattle herds are given in Table 17. The population projection matrices are derived using the demographic rates given in Table 16. The matrix is applied to initial cattle herd to provide cattle herd growth dynamics over time. The parameters of population projection matrix determines whether the cattle herd is declining, held constant or growing over time. The parameters also reflect the state of cattle productivity development and are affected by the changes in policy and investment interventions in the MRS production system.

Table 17. Annual Lefkovitch stage-structured population projection matrices for cattle herds in the MRS cattle production system

Stage at year t+1	Stage at year t					
	Fj	Fs	Fa	Mj	Ms	Ma
Small herd size						
Fj	0.00	0.00	0.27	0.00	0.00	0.00
Fs	0.88	0.47	0.00	0.00	0.00	0.00
Fa	0.00	0.41	0.91	0.00	0.00	0.00
Mj	0.00	0.00	0.27	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.80	0.44	0.00
Ma	0.00	0.00	0.00	0.00	0.33	0.91
Medium herd size						
Fj	0.00	0.00	0.29	0.00	0.00	0.00
Fs	0.92	0.31	0.00	0.00	0.00	0.00
Fa	0.00	0.57	0.91	0.00	0.00	0.00
Mj	0.00	0.00	0.30	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.85	0.30	0.00
Ma	0.00	0.00	0.00	0.00	0.53	0.91

Source: Simulation results.

Simulation of baseline cattle herd growth dynamics

Cattle herd growth rates, stable stage distributions and stage-specific reproductive values

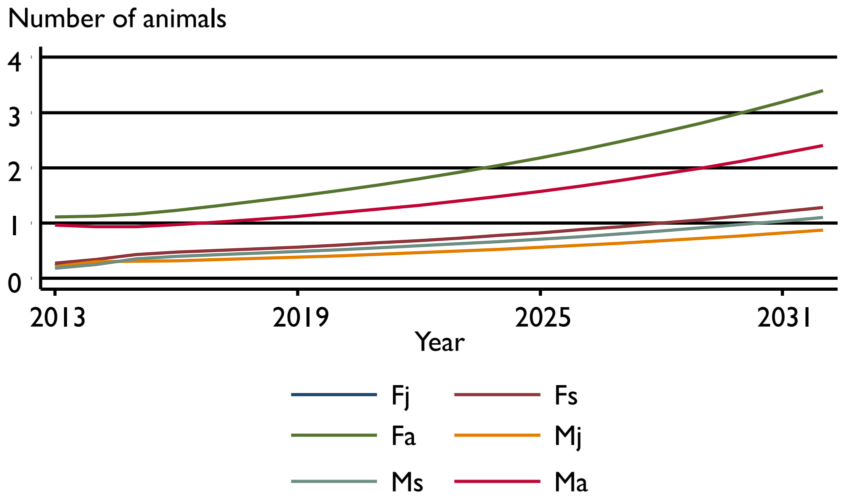
The baseline stable stage distribution, stage-specific reproductive values and annual long-term cattle population multiplication rates for the MRS production system are given in Table 18. The projection of livestock numbers for different classes of cattle in MRS production system are given in Figures 6 and 7. There is upward trend for all cattle types for both small and medium herd size MRS. It is observed that under the baseline scenario, the long-run cattle multiplication rate for small and medium herd size MRS production systems are 1.06 and 1.09, respectively, which imply a 6% and 9% annual cattle growth rate, respectively. The stable stage distribution associated with this constant cattle growth rate for small-sized herd is 9%, 13%, 34%, 9%, 11%, and 24% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male cattle, respectively. The stable stage distribution is also dominated by female cattle, especially adult females. It is also observed that the adult female contributes most to the cattle reproductive value followed by sub-adult female. The reproductive value of male cattle is assumed to be zero in this kind of cattle growth modelling. Similar stable stage distribution and stage-specific reproductive values are observed for both small- and medium-sized herd MRS production system.

Table 18. Baseline stable stage distribution (w), stage specific reproductive values (v) and annual long-term population multiplication rate and per capita growth rate for the MRS cattle production system

Sex-stage class	Small-sized		Medium-sized	
	w	v	w	V
Fj	0.09	1.00	0.09	1.00
Fs	0.13	1.21	0.11	1.19
Fa	0.34	1.75	0.33	1.61
Mj	0.09	0.00	0.09	0.00
Ms	0.11	0.00	0.10	0.00
Ma	0.24	0.00	0.28	0.00
Λ	1.06		1.09	

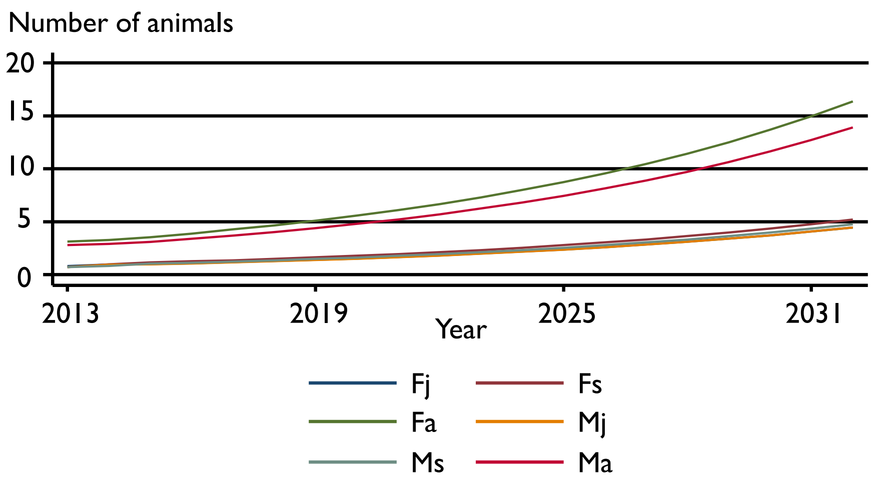
Source: Simulation results.

Figure 6: Number of cattle by sex and stage of growth, MRS small herd



Source: Simulation results.

Figure 7: Number of cattle by sex and stage of growth, MRS medium herd



Source: Simulation results.

Sensitivity and elasticity analysis

The results of sensitivity and elasticity analyses for the MRS production systems are given in Table 19. The results of elasticity analyses show that the long-term cattle population growth rate is most elastic to the probability that an adult female survives and persists as an adult. The adult female survival rate contributes more than 59–61% to the cattle herd growth in MRS production system. The annual population growth rate is second most elastic to the probability that sub-adult female survives and stays as a sub-adult. For example, a 1% increase in sub-adult survival rate of cattle in MRS production system results in about 17–18% increase in the annual multiplication rate. In terms of stages of growth, it is also interesting to note that young female cattle, sub-adult and adult stage contribute 10%, 18%, and 71%, respectively, to cattle herd growth in small herd MRS production systems. Furthermore, it is also important to note that the female cattle fertility contributes only 10–12%, while the annual survivorship contributes about 88–90% to the cattle growth rate. Thus, similar to other cattle production systems, under the baseline scenario, it is more important to reduce mortality rate than improving the fertility of cattle to increase cattle growth in MRS production systems.

Table 19. Sensitivity and elasticity matrices from Lefkovitch stage-structured population projection matrix for the MRS cattle production system

	Sensitivity matrix			Elasticity matrix			
	Fj	Fs	Fa	Fj	Fs	Fa	Total
Small herd size							
Fj	0.00	0.00	0.40	0.00	0.00	0.10	0.10
Fs	0.12	0.18	0.00	0.10	0.08	0.00	0.18
Fa	0.00	0.27	0.71	0.00	0.10	0.61	0.71
Total				0.10	0.18	0.71	
Medium herd size							
Fj	0.00	0.00	0.44	0.00	0.00	0.12	0.12
Fs	0.14	0.17	0.00	0.12	0.05	0.00	0.17
Fa	0.00	0.23	0.71	0.00	0.12	0.59	0.71
Total				0.12	0.17	0.71	

Source: Simulation results.

Simulation of steady state cattle herd growth dynamics

Stable stage distributions, stage-specific reproductive values and commercial offtake rates

The steady-state stable stage distribution, stage-specific reproductive values and commercial offtake rates for the MRS production system are given in Table 20. The steady state cattle production is obtained by numerically adjusting the commercial offtake rates by sex and stage of cattle growth. This indicates that in order to obtain steady state cattle production there is a need to decrease the cattle herd size by decreasing certain types of cattle which significantly contribute to cattle growth. Thus, the zero cattle growth rate is obtained by increasing the commercial offtake of female cattle mainly sub-adults and adult female cattle. As a result, under steady state the percentage offtake of sub-adult female cattle substantially increased.

Table 20. Steady-state stable stage distribution (w), stage specific reproductive values (v) and offtake rates for the MRS cattle production system

Sex-stage class	Small herd size			Medium herd size		
	w	v	Offtake rate	W	v	Offtake rate
Fj	0.07	1.00	0.00	0.06	1.00	0.00
Fs	0.11	1.14	0.07	0.08	1.09	0.08
Fa	0.28	1.54	0.12	0.24	1.35	0.15
Mj	0.07	0.00	0.05	0.06	0.00	0.05
Ms	0.10	0.00	0.15	0.08	0.00	0.10
Ma	0.37	0.00	0.05	0.46	0.00	0.05

Source: Simulation results.

Beef and milk production

The annual steady state beef production (total carcass weight) and milk production by different cattle production systems is given in Table 21. The average annual live cattle offtake rate for the small and medium-sized cattle herd is 8%. The average annual beef production for small- and medium-sized herd is 30 kg/herd and 100 kg/herd, respectively. In terms of milk production, the annual average milk production for small and medium-sized cattle herd is 204.0 litre/herd and 687.0 litre/herd, respectively.

Table 21. Steady state beef production and cumulative and annualized present value of gross margins by different cattle production systems in Ethiopia[1]

Production system	Average net offtake (%)	Average annual beef production from the herd (Kg/herd)[2]	Average annual milk production (litre/heard)	Annualized present value of value added beef (ETB)	Annualized present value of beef per head of cattle (ETB/head)
MRS					
Small herd size	8	30	204.0	27,356	9119
Medium herd size	8	100	687.0	42,243	4694

Note: [1]The time horizon for the projection is 28 years. [2]The annual beef production is in carcass weight equivalent assuming 45% to 50% dressing percentage.
Source: Simulation results.

Financial profitability

The results of the analysis of financial probability of beef production at steady state cattle production is given in Table 21. The annualized present value of *GM* for cattle production per herd and head of cattle are given in Table 21. The annualized present value of cattle outputs per herd of cattle for small and medium herd MRS cattle herd is estimated to be ETB27,356 and ETB42,243, respectively. On the other hand, the annualized present value of *GM* for cattle outputs per head of cattle for small and medium herd is ETB9119 and ETB4694, respectively. The small-sized cattle herd appears to be more productive.

5.2 *Ex-Ante* impact assessment of policy and investment interventions

5.2.1 Description of bio-economic simulation analysis

The baseline assessment of traditional cattle production systems in Ethiopia, based on the review of literature and expert opinions indicate that there is very high level of mortality rate for the cattle reared across the major livestock production systems. The causes of these high levels of mortality rates are hypothesized to be due to the higher incidence of livestock diseases, internal and external parasites, and inadequate animal feeding and management practices. The negative impact of such livestock diseases on the household income, food security and national economy is well-established.

First, for the poor livestock producers, who subsist or survive on just a few animals for living as a source of food, income, means of production and main productive assets, the death of animals due to disease or productivity losses has tremendous impact on their well-being. Second, livestock diseases also hinder the poor smallholder farmers from accessing and competing in domestic and global livestock and livestock product markets. Third, the livestock mortality caused due to diseases or other factors reduces the competitiveness of commercially-oriented livestock production through direct economic losses resulting from animal deaths and decreased productivity from morbidity associated with animal diseases and parasites, and inadequate management practices. Fourth, disease affects the national economy by decreasing the foreign exchanges earned from livestock exports by limiting their access to international markets. Finally, important negative externalities of livestock disease include impacts on the health of other producers' livestock and on human health.

Given the fact that livestock mortality and morbidity are important causes of economic losses and food insecurity, and poverty, appropriate disease control measures are necessary to reduce the negative impacts of livestock diseases and parasites on households and the national economy. The high incidence of disease indicates the lack of adequate investment in animal health and management practices. However, the funds available for various interventions are also limited which require *ex-ante* the assessments of the economic impacts, technical feasibility and cost-effectiveness of the proposed investment interventions to reduce livestock mortality due to livestock diseases and inadequate management practices. The bio-economic simulation analysis is discussed in section 4 is applied to analyse *ex-ante* the impacts of combined animal health and feed management interventions in cattle production in different production systems.

The combined investment interventions in animal health, feeding and management practices to reduce young stock and adult stock mortality was determined based on a serious of consultative discussions among the senior staff of the State Ministry of Livestock and livestock master plan team. The suggested interventions involve changes in public and private sector veterinary service provisions and public investments in animal feeds, health and nutrition. Accordingly, the combined investment interventions proposed to reduce young stock and adult stock mortality are improvements in access to and quality of veterinary health services through rationalizing public and private veterinary sector services, improvements in feeding and management practices. The specific actions required are: creating enabling environment and road map for rationalization of public and private sector tasks; setting up a statutory body to regulate the veterinary profession; gradual decrease in subsidies given in public veterinary clinics (on services and drugs); and incentives (credit and subsidies) for setting up private veterinary clinics in remote areas and by young veterinarians in all areas. The investment interventions are expected to result in adoption of new technologies such as the use of anti-parasitic control drugs and vaccinations for transboundary animal and other diseases.

It is assumed that under baseline scenario the animal population currently reached by veterinary health service is 30% and the percentage of animal population at risk that is targeted by the interventions are 70% of the population. The adoption rate for interventions is assumed to progress slowly. The adoption rate is expected to reach 20% by fifth year of the project; 40% by tenth year; 80% by fifthteenth year of the project; and assumed to remain the same until the twentieth year of the project. The combined investment intervention is expected to result in the reduction in young stock mortality by 20% over 20-year investment time horizon and in the reduction of older stock mortality by 10% over the same 20-year investment time horizon.

The initial investment cost of the intervention was estimated at ETB 1 billion to be equally spent over three years. The total investment cost was assumed to be secured from government sources. The intervention involves cattle, camel, sheep and goats in the major livestock production systems (LG, MRD and MRS). The annual recurrent costs associated with investment costs for individual livestock species are given in Table 22. The implementation of young stock immunization through vaccination against foot-and-mouth disease (FMD) for cattle is assumed to cost ETB10/dose and two doses/head per year or ETB20/head per year is required.

Table 22. Assumptions on annual recurrent costs associated with investment costs to reduce young stock mortality (ETB/head)

Animal health intervention cost item	Costs (ETB/head)			
	Cattle	Camel	Sheep	Goats
FMD	20	20	10	10
Costs of vaccines (package)	13	13	7	7
Anti-parasitic drugs (dipping or spraying)	14	14	6	6
Extension service (feed, housing, and sanitation)	1	1	0.5	0.5
Annual disease surveillance	1	1	0.5	0.5
Additional cost for improved veterinary service	4	3	1	1
Total annual recurrent costs (ETB/head)	53	52	25	25

Source: Simulation results.

The vaccination cost required for animal export diseases of trade (transboundary animal diseases, such as PPR, CBPP, CCPP, etc.) is estimated at an unsubsidized cost of ETB13/head per year for cattle. Cattle will be also treated against internal and external parasites. The treatment against internal and external parasite is assumed to be ETB14 /head for cattle. The vaccination service charge is assumed to be ETB1/head on average. The additional cost for improved veterinary service per head is ETB5 for cattle.

In addition to disease control and preventive measures, the investment intervention also involves livestock disease surveillance. The annual cost of implementing disease surveillance is estimated at ETB1/head for cattle. The technical advisory support for livestock keepers to improve their livestock husbandry practices will be implemented through extension services. The additional annual extension services is estimated at ETB1/head for cattle to achieve improved management in animal feeding, housing and better sanitation. In general, the total investment cost per animal affected per year for vaccination and anti-parasitic drug is estimated at ETB53/head for cattle.

To realize the impact of animal health interventions, there have to be also complementary improvement in the animal feeding and management practices and is discussed next. The adequate feeding of the pregnant animal at the latter stages of pregnancy and early stage of lactation by providing more concentrates is suggested. This is assumed to cost about ETB3/kg for cattle. The amount of concentrate recommended varies by classes of animals. First, in the case of cattle it is recommended that a 0.5 kg concentrate provided to the dam for three months over two years. This is expected to increase milk yield by 1 kg and half of it (0.5 kg) goes to the calf, resulting in incremental weight gain of 22 g/day. The remaining 0.5 kg of the milk is sold to increase the income of the livestock keeper.

Results of *ex-ante* impact assessment of policy and investment interventions

The potential productivity, output, income and costs effects of the suggested investment interventions in the cattle sub-sector are analyzed *ex ante* at different levels: at household or herd level, typology of livestock production zones level and national level. The *ex-ante* financial profitability of cattle policy and investment interventions are based on 20-year projected incremental cash flows comparing 'with' and 'without' intervention scenarios following a partial budgeting approach as discussed in section 4. The 'without' intervention scenario provides a counterfactual scenario against which to compare the impacts of policy and investment interventions in cattle production. For this purpose, the household-level partial budgets—the building blocks for *ex ante* financial analysis—were constructed for different cattle size classes by different production systems and then the projected cash flows were derived in terms of incremental benefits; incremental costs; and incremental net benefits due to the project (investment interventions) only. The following sections present the results of *ex-ante* assessment of policy and investment interventions in cattle production in terms of its financial profitability, impacts on future production–consumption balances and household level-income impacts.

Impacts on future production–consumption balance

The future impacts of policy and investment interventions on cattle production is also assessed *ex-ante* in terms of closing the rapidly growing production–consumption gap or generating surpluses of beef and milk products for export markets to generate foreign exchange earnings. This projection is also critical to anticipate the magnitude of required future strategies and investments in cattle research and development (policies and technologies), which will be required to close the production–consumption gap in beef and milk production. Considering 15-year projection period (2012–32), the results for beef and milk are presented in Tables 23 and 24, respectively.

Under the 'without' intervention scenario, the projected total production of beef in 2028 is about 1 million metric tonnes. The projected total consumption of beef is estimated at 2.3 million metric tonnes, so the domestic production will not be sufficient to meet the projected beef consumption requirements. Thus, the projected self-sufficiency rate for beef in 2028 is about 43%. There will be a beef deficit of 1.3 million metric tonnes. 'Without' investment intervention there will be huge deficit in beef supply. Therefore, investment is required to close the production–consumption gaps for beef. The projected beef production with combined investment interventions is estimated at 1.8 million metric tonnes in 2028 (Table 23). The investment intervention increases self-sufficiency ratio from 43 to 80%. However, even with the interventions, there will be a significant beef deficit of about 20% in the future.

Table 23.Projected national production, consumption, and production and consumption balance of beef 'with' and 'without' combined investment interventions in Ethiopia by 2028

Status of intervention	National production	National consumption	Production–consumption balance (103 t) +	Production as a per cent of consumption (%)
	(103 t)	(103 t)		
'Without'	985	2301	-1316	43%
'With'	1794	2301	-508	78%

Note + Negative values indicate deficits while positive values indicate surpluses. The beef is measured in terms of carcass equivalent of net live cattle offtake.
Source: Simulation results.

The results of projections of the production and consumption of cow milk 'with' and 'without' investment interventions are presented in Table 24. 'Without' investment intervention, the total cow milk production in 2028 is projected at about 6.5 billion litres. As a whole, 'without' investment intervention the self-sufficiency ratio in cow milk production is about 77 % (with a deficit of 2.0 billion litres). Therefore investment is also needed to close the future cow milk production–consumption gap. The combined policy and investment interventions resulted in a significant improvement in the self-sufficiency ratio for cow milk from 77–136%.

Table 24. Projected national production, consumption, and production and consumption balances of cow milk 'with' and 'without' combined investment interventions in Ethiopia by 2028

Status of intervention	National production	National consumption	Production–consumption balance (106 litre)+	Production as a per cent of consumption (%)
	(106 litres)	(106 litres)		
'Without'	6480	8439	-1958	77%
'With'	11,453	439	3015	136%

Note + Negative values indicate deficits while positive values indicate surpluses.
Source: Simulation results.

In general, the analysis of the 'without' investment interventions situation indicates that beef and milk production will have to be increased significantly if future demand for domestic consumption is to be met and surplus beef and milk are to be generated to meet the future meat and milk export demand. The main question is then from where does the future increase in meat production come? Several strategies can be considered to close the gap in future beef and milk productions. First, the analyses of 'with' investment situation indicate that the future beef and cow milk production gaps can be significantly bridged with combined investment interventions in various aspects of cattle production and management systems. Second, it is also important to exploit the opportunity to close the deficits in production–consumption balances by changing the composition of livestock production and demand structure. For example, there is a need to explore the opportunity to change the meat production and consumption structure from the one dominated by red meat to chicken meat and meat from small ruminants (sheep and goats). This strategy requires investments in poultry and small ruminant productions and the promotion of chicken meat and small ruminant meat consumption as a substitute for beef. The improvement of cattle productivity through genetics is also required in the future.

Impacts on financial profitability

The results of the *ex-ante* financial profitability of the combined investment analyses by cattle production systems in Ethiopia are given in Table 25. The *NPVs* are positive in all cases, all the *IRRs* are greater than the assumed discount rate of 10% and the *BCR* is also greater than 1 in all cases. In general, all the financial performance criteria used indicate the financial viability of combined cattle policy and investment interventions by cattle production systems in Ethiopia. It is important to note that there are also several social and cultural benefits of cattle which are difficult to express in monetary terms and consequently not included in the analysis of financial profitability. As a result, the total benefit of cattle production might be underestimated.

Table 25. Returns to combined policy and investment interventions in cattle production by cattle production systems in Ethiopia (2013–2032)

Cattle production system	Herd size group	Indicators of return to investment*		
		NPV (106 ETB)	*IRR* (%)	*BCR*
MRS	Small	13,335	43	2.43
	Medium	30,883	29	1.68
MRD	Small	784	44	2.48
	Medium	3414	48	3.04
LG	Small	3120	25	2.49
	Medium	2707	36	2.63
	Large	14,639	44	2.98

Note: * Indicates that the investment analysis was made for 20 years assuming 10% discount rate (opportunity cost of capital).
Source: Simulation results.

Impacts on household income

In order to assess the household level income and poverty impacts of cattle policy and investment interventions, the 20-year cumulative incremental benefits and costs from combined policy and investment interventions were annualized assuming a discount rate of 10%. The results are presented in Table 26. Five performance measures were derived: annual incremental benefits per herd; annual incremental costs per herd; annual net incremental benefits per herd; annual net incremental benefits per head of cattle; and annual incremental per capita income. The annual incremental costs include both capital investment and recurrent costs. The size of annual incremental costs required indicates whether the investment or costs of investment interventions are within the reach of livestock keepers. The annual net incremental benefit is obtained as the difference between annual incremental benefits and annual incremental costs. The annual net incremental benefit per head of cattle is obtained by dividing the annual incremental net benefit per heard by cattle herd size. This measures the productivity of cattle in different production systems. The annual net incremental per capita income is obtained by dividing the annual net incremental benefit by average family size (assuming an average farm family size of 4.7 people). The results are presented by cattle production systems and cattle herd size classes.

Table 26. Summary of discounted benefits and costs due to combined investment interventions in cattle production by production system in Ethiopia

Cattle production system	Herd size group	Annual incremental benefits (ETB/herd)	Annual incremental costs (ETB/herd)	Annual net incremental benefit (ETB/herd)	Annual net incremental benefit(ETB/ head of cattle)	Annual net incremental benefit per capita income (ETB)
MRS	Small (3)*	2632	1065	1566	522	333
	Medium (9)	8937	5309	3627	403	772
MRD	Small (2)	154	62	92	46	20
	Medium (6)	598	197	401	67	85
LG	Small (9)	612	246	367	41	78
	Medium (7)	513	195	318	45	68
	Large (18)	2587	867	1719	96	366

Note: * The figures in parenthesis indicate the cattle herd size.
Source: Simulation results.

The income impact of combined investment intervention in cattle production varied by cattle production systems and cattle herd size classes. The highest income impact is observed in the MRS production system followed by LG and MRD. Within each production system, it is observed that the higher the cattle herd size, the higher the incremental net benefit of the investment intervention. This result indicates the importance of the production system in which cattle are raised and the cattle herd size in influencing the return to cattle investment. The results by herd size indicates economies of scale in cattle production, while the results by production system indicates the difference in productivity levels due to differences in costs of production and marketing, market infrastructure, and access to markets. In general, the *ex-ante* assessment indicate that combined policy and investment interventions in cattle production substantially enhances the returns to cattle production under different production systems. It is also observed that larger cattle herd sizes are more productive in all production systems and indicate the importance of economies of scale in raising cattle productivity.

In MRS, the highest annual incremental per capita income of ETB772 is obtained from the investment in the medium-sized cattle farm followed by the small-sized cattle farm with average annual incremental per capita income of ETB333, almost half of the annual incremental per capita income for the medium-sized cattle farm. In the case of MRD, the highest annual incremental per capita income is observed for medium-sized cattle farm. In the LG, the highest annual incremental per capita income of ETB366 is also obtained from large-herd sized farm followed by small-sized herd.

6. Conclusions and policy recommendations

The objective of this paper is to develop analytical and empirical modelling framework which integrates cattle herd growth and economic model for simulating cattle production. The modelling framework allows for assessing the technical and financial performance of cattle production under two conditions: 'without' intervention and 'with' intervention. The bio-economic simulation analyses of cattle production for different production systems for the 'without' intervention situation is used to assess and identify potential areas for policy and investment interventions to improve the future performance of cattle sub-sector in Ethiopia. The data on cattle size and structure, demographic parameters and financial parameters used in the bio-economic simulation model are obtained from secondary sources: based on national and international livestock experts' opinions, literature review and analysis of cross-sectional household survey data from secondary sources.

The baseline assessment of the cattle production systems indicate that the cattle sub-sector is characterized by high mortality rates, low fertility and low commercial offtake rates. The average cattle herd size observed is very small, particularly in the mixed crop livestock production system. A bio-economic simulation model for the 'without' intervention situation indicates that the cattle production in different production systems is growing at annual growth rate of 5–10%. The baseline assessment also indicates that adult female cattle is the most important classes of cattle, explaining the various future cattle population growth trajectories.

Under baseline situation, it is observed that the small cattle herd size does not allow substantial and meaningful commercial offtake. The financial return to cattle keepers is also very small due to the small cattle herd size which does not support large commercial offtake (meat and milk) on sustainable basis. Building cattle herd with appropriate herd structure by taking into account the feed availability and access to market might be important in some situations in order to allow cattle keepers to take advantage of market opportunities.

In general, it appears that in response to the emerging market opportunities, the capacities and methods of livestock production and marketing practices of smallholder farmers and pastoralists and agricultural extension services have changed very little. In order to take advantage of the emerging livestock market opportunities, there is a need to explore different alternative strategies of increasing the supply of quality cattle and cattle products for domestic as well as for export markets. This needs to be informed by rigorous bio-economic simulation analysis based on reliable and representative technical and financial data. The demographic data need to be revised and updated regularly through more rigorous and systematic way of data collection—cross-sectional and longitudinal surveys.

The observed low level of productivity in cattle indicates the need to invest in cattle genetic improvement, health, reproductive management and nutrition. Particularly, the results of sensitivity and elasticity analyses indicate that the female cattle fertility contributes only 9–10%, while the annual survivorship of adult female cattle contributes about 59–61% to the cattle herd growth rate. Thus, under the baseline scenario, it is more important to reduce the mortality rate than improving the fertility of cattle to increase cattle herd growth in different production systems. This indicates the importance of identifying the causes of cattle mortality and implementing cost-effective measures to reduce it. This requires detailed *ex-ante* benefit–cost analysis of various interventions using bio-economic simulation model as outlined in this paper. Here, the bio-economic simulation model is applied to the *ex-ante* impact assessment of the proposed combined investment interventions to reduce young and adult stock mortality in cattle.

The results of bio-economic simulation analysis indicate that the combined investment interventions in cattle health, feeding and management practices to reduce young stock and adult stock mortality is financially viable and enhances Ethiopia's beef and milk self-sufficiency ratio and has a significant impact on cattle keepers income. The implementation of the proposed combined investment intervention requires strong private and public partnership and involves changes in public and private sector veterinary service provisions and public investment. Some of the key policy recommendations include:

- Improvements in cattle producers' access to quality feed at reasonable price;
- Improvements in cattle extension and advisory services;
- Improvements in access to livestock markets and information;
- Improvements in access to financial services;
- Improvements in cattle farm management practices;
- Improvements in access to and quality of veterinary health services through the rationalization of public and private veterinary sector services, and improvements in feeding and management practices
- The establishment of an enabling environment and a road map for the rationalization of public and private sector tasks;
- The establishment of a statutory body to regulate the veterinary profession;
- The gradually decrease of subsidies given in public veterinary clinics (on services and drugs);
- The provision incentives (credit and subsidies) for the establishment of private veterinary clinics in remote areas and by young veterinarians in all areas;
- The promotion of the adoption of new technologies such as the use of anti-parasitic control drugs and vaccinations for transboundary animal and other diseases;
- The delineation of the role of the public and private sectors in animal health based on the nature of the goods. This should include:
  - The preparation of a policy statement which clearly defines public and private tasks;
  - Full cost recovery by the public sector of private good tasks (such as clinical services) to avoid competition with the private sector;
  - The gradual withdrawal of the public sector from clinical services;
  - The establishment of sanitary mandate—the delegation of certain public good activities to the private sector; and
  - The provision of loans for interested private service providers.

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Livestock and irrigation value chains for Ethiopian smallholders project aims to improve the competitiveness, sustainability and equity of value chains for selected high-value livestock and irrigated crop commodities in target areas of four regions of Ethiopia. It identifies, targets and promotes improved technologies and innovations to develop high value livestock and irrigated crop value chains; it improves the capacities of value chain actors; it improves the use of knowledge at different levels; it generates knowledge through action-oriented research; and it promotes and disseminates good practices. Project carried out with the financial support of the Government of Canada provided through Foreign Affairs, Trade and Development Canada (DFATD). lives-ethiopia.org

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