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1 Introduction

1.1 Background and justification

Ethiopia's livestock production is characterized by mixed-species and multi-purpose type and the development of intensive commercially oriented specialized (single species or single purpose) livestock production is at its early stage. Sheep are found to be an integral part of these types of livestock production systems. There are about 15 known major local sheep breeds raised in different agro-ecological zones of the country (Awgichew and Abegaz 2008). Ethiopia has the largest sheep population in Africa. In 2013, the most recent comprehensive estimate of sheep population, based on the compilations of data from different sources, indicate that there are about 29 million heads of sheep distributed among the major livestock production systems in the country; agro-pastoral and pastoral (50%) and the highland mixed crop–livestock production systems (50%.) (LSA, forthcoming 2016).

In general, sheep are raised in Ethiopia both in the highland mixed crop–livestock production systems and in the lowland agro-pastoral and pastoral livestock production systems. Similar to other ruminants like cattle and goats, sheep also provide multiple outputs to livestock keepers; they are a source of relatively affordable nutritious food (meat); produce organic manure for crop production; generate cash income from the sale of live sheep, sheep meat or skins; and represent a form of asset that can easily be liquidated for emergency situations and small cash requirements. In Ethiopia, dairy sheep or keeping sheep for milk production is not known. In some areas, sheep are also raised for wool production. In general, the potential of sheep contribution towards improving farm households' income and food security situations and national economic growth in developing countries like Ethiopia is tremendous. However, despite its economic potential, sheep production is also besieged by several constraints affecting its productivity and production and hence limiting its contribution towards improving farm household income and food security, poverty reduction and national economic growth. Similar to goats production system, the sheep production system in Ethiopia is also characterized by poor genetic performance and a high level of morality due to poor management practices, feed scarcity, and inadequate animal health services and prevalence of animal diseases (Gebremariam et al. 2013; Gizaw et al. 2013; Haile et al. 2011; Negassa et al. 2011; Gizaw et al. 2010; Negassa and Jabbar 2008; Tolera 2007).

Sheep are kept by large number of pastoral, agro-pastoral and smallholder farmers in Ethiopia. For example, Negassa et al. (2011) indicate that 20% and 38% of the agro-pastoral and pastoral households and smallholder farmers, respectively, own sheep. However, the size of their ownership is very small and their productivity level is also observed to be one of the lowest in eastern Africa (Negassa et al. 2011). For sheep producers to benefit from the rising demand for sheep meat and products, they need to have an adequate number of sheep that can generate sufficient marketable surpluses of sheep on sustainable basis. Particularly, given the limited land resources for feed production and environmental constraints to increasing livestock production, it is important to increase the productivity of the sheep production from the limited existing sheep flock and land holdings. In this regard, an understanding of the baseline sheep performance and flock growth dynamics is very important to examine the evolution of sheep flock size and structure over time and to identify potential targets for different interventions to increase sheep producers' profits and their volume of participation in live sheep and sheep products markets on sustainable basis.

The full realization of the potential of sheep require investment to improve sheep production management, especially in feeding and disease control for improving sheep growth and reproductive rates along with creating an enabling environment (institutions, infrastructure and policies) to allow producers to take advantage of growing sheep market opportunities. However, the investment resources are very scarce and detailed sheep sub-sector sector analyses in terms of identifying and prioritizing investment opportunities and constraints in the sub-sector sector are critical for effective and efficient utilization of the scarce investment resources.

Currently, there are no comprehensive *ex-ante* impact assessments of policy and investment interventions and *ex-ante* analytical and empirical modelling frameworks for guiding and prioritizing public and private investment decisions to promote the development of sheep sub-sector in Ethiopia. This paper develops and implements an empirical bio-economic sheep flock growth model to analyse the sheep's flock growth dynamics and its economics to inform the various policy changes and investment strategies to develop the sheep sub-sector. It builds on previous detailed livestock sector analyses for Ethiopia by the International Livestock Research Institute (ILRI) jointly with the Livestock State Ministry of Ethiopia using the Livestock Sector Investment and Policy Toolkit (LSA) developed by the World Bank and Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) (LSA 2013). It focuses on detailed analyses of sheep flock growth dynamics for representative livestock production systems which allows *ex-ante* impact assessment of policy and investment interventions and thus can inform and guide strategic development in infrastructure, institutional, technological and management practices that support significant increase in sheep production, productivity and commercial offtake. The modelling framework provides information on economics of sheep production at different scales (flock level and production system level) and can be aggregated at regional or national level, thus making it possible to prioritize investment in the research and development of sheep at regional or national level.

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 sheep flock growth model with and economic model for simulating sheep meat and milk production for *ex-ante* assessment of the financial profitability of investment interventions to improve sheep production in mixed crop–livestock and agro-pastoral and pastoral production systems in Ethiopia. The specific objectives are:

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

This paper is organized as follows. The next section provides brief description of the data used in the analysis. Section 3 presents 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 made 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 livestock sector analysis report for Ethiopia (LSA forthcoming 2016). The data has been obtained from different secondary sources. First, the initial sheep flock size and structure data is 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 pastoral areas of Ethiopia. Second, the sheep demographic data (for example, fertility rates, mortality rates and offtake rates) used to generate parameters for various sheep flock projection matrices was collected using the Delphi technique which involved the use of a structured questionnaire to collect technical data from the national and international livestock experts. The data collected using the Delphi method was validated through panels of expert meetings and discussions. Third, the costs of production for different livestock enterprises and prices for the valuation of livestock and livestock products were also obtained from the expert interviews and secondary sources. This study focuses on agro-pastoral and pastoral and mixed crop livestock production systems which account for most sheep population and livestock dependent population. There is a trend towards intensive specialized commercial livestock production systems, but the scale is still not significant, and therefore, it is not considered in this paper.

3. Analytical framework

The analytical framework for Livestock Sector Investment Policy Toolkit (LSIPT) is a dynamic bio-economic simulation modelling. A non-stochastic dynamic sheep flock growth model is used for the projection of the sheep population and outputs from sheep production (meat, or manure) over a fifteen year time period. The model also allows the simulation of sheep production outputs given inputs required for sheep production. Then, the flock model is linked with an economic model to allow the evaluation of financial and economic profitability of sheep production over the same time period based on a proper valuation of goat production inputs and outputs. The simulation analysis allows the assessment of the technical and financial performance of the sub-sector over time given the input use, existing technologies, market conditions and policies facing the sub-sector. The analysis is conducted at flock level, but the results of the simulation analysis can be aggregated at different levels: production system level, at regional and national level. The baseline assessment provides a counterfactual scenario ('without' intervention) against which new sheep policy and investment 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 sheep sub-sector to farm household income growth, food security, poverty alleviation and national economic growth.

4. Empirical approach

4.1 Stage-structured sheep flock projection matrix model

The population projection matrices are based on Leslie (1945); Caswell (1989); and 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); and 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, requires age-specific demographic data) and mathematically more demanding (due to higher dimensions of matrices used) as compared to the stage-structured Lefkovitch matrix model. Moreover, in terms of application, the stage-structured matrix is more practical, for example, as the utilizations of sheep or any livestock for different purposes are mainly based on stages of growth (age ranges) rather than 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 prediction. In this paper, the Lefkovitch sex and stage-structured population projection matrix model is used due to its relative simplicity computationally and realistic characterization of sheep growth stages.

In a Lefkovitch stage-structured sheep population projection matrix model, the structure of the sheep flock is defined in terms of animal numbers in different age classes and sex cohorts. Thus, the female and male sheep are divided in to three discrete growth stages based on age: juvenile, sub-adult and adult. In general, the stage durations for sub-adults and adult sheep are assumed to be different by sex of sheep and by production system analysed. The projection interval, or time step, used for the projection is one year and the overall sheep population projection time horizon is 20 years. The flock growth model is run by different flock size classes and for major production systems to see the effects of flock size and production system on sheep flock growth dynamics.

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

$$\boldsymbol{n}_{t+1} = \boldsymbol{A}\boldsymbol{n}_t \qquad (1)$$

Where $\boldsymbol{n}_{t+1}$ denotes the 6x1 state vector of sheep flock sizes by sex and by stage of sheep growth at a time $t+1$; $\boldsymbol{n}_t$ is a 6x1 state vector of sheep flock size by sex and stage of sheep growth at time t; and $\mathbf{A}$ is a square 6x6 Lefkovitch annual stage-structured population projection matrix used to analyse sheep population dynamics in discrete time (Lefkovitch 1965). The A matrix is used to generate a new state variable or vector n_{t+1} and contains the annual transition probabilities derived 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 sheep which is the product of annual parturition rate and net prolificacy rate, the subscripts *j*, *s* and *a* denote juvenile, sub-adult and adult goat, respectively irrespective of the sex of the sheep and $G_{i,j}$ is the probability that a sheep 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 sheep 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 the sheep 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 the Leslie matrix is given in terms of fecundities in the first row which indicate the reproductive contribution for different sheep 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 sheep 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 et al. (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 flock growth model or endogenous population dynamics model where animals are not imported from outside the population to accelerate growth (Lesnoff 2012). Thus, the sheep demographic behaviour is assumed to be influenced mainly by both 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 sheep 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 since this represents a natural breeding system. Note that the 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 sheep (F), while the entries in the lower blocks are for the male sheep (M). 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 setup, the next step in the analysis of sheep flock dynamics is to find out the eigenvalues and eigenvectors of the population projection matrix A. Several important parameters which characterize the sheep flock 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) sheep population multiplication rate, while log (λ**)** gives intrinsic annual growth rate which is the continuous growth rate per individual sheep in the population. Thus, in the long-run the sheep population follows exponential growth rate given by log (λ**)** or**:**

$$\boldsymbol{\lambda = e^{r}} \quad (7)$$

$$\boldsymbol{\lambda^{t} = e^{rt}} \quad (8)$$

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:

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

Where *det* denotes determinant and I is an identity matrix. The sign of λ indicates whether the flock size (or population) is declining ($\lambda <1$), the sheep flock size is staying constant ($\lambda=1$)**,** or the sheep flock size is increasing ($\lambda >1$) 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 increases by 20% per year and λ equal to 0.93 means the population will decrease by 7% per year over the long run. Second, the normalized eigenvector (w) associated with the dominant eigenvalue gives the stable stage-structured proportion for sheep flock 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 sheep production as compared to the juvenile, this measures the relative contributions of different stages of sheep growth to long-term growth in sheep flock 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 equilbrium:

$$\boldsymbol{Aw} = \lambda * \boldsymbol{w} \quad (10)$$

From equation (10) it follows that the sheep projection equation (1) can be alternatively given as:

$$\boldsymbol{n}_{t+1} = \lambda * \boldsymbol{n_t} \quad (11)$$

For T large, λ is also approximated by annual empirical multiplication rate given as the ratio of Nt+1 to Nt 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 sheep projection model at any time t given the initial flock size and stable flock proportion as:

$$\boldsymbol{n}_t = n_0 * \lambda^t * \boldsymbol{w} \quad (12)$$

Where n_t is a vector of sheep population at time *t*; n_0 is scalar and denotes the initial sheep flock size; λ is the dominant eigenvalue and w is the normalized eigenvector associated with the dominant eigenvalue and denotes stable stage population proportions. Similarly, given the stable sex and stage distribution, and asymptotic sheep growth rate, the total commercial live sheep offtake for sheep with i^{th} sex in j^{th} growth stage at any time *t* can be obtained using the following commercial offtake function:

$$O_{ij,t} = O_{ij} * n(0) * \lambda^t * \boldsymbol{w} \quad (13)$$

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 sheep 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 sheep growth rate and stable stage-structure w.

It is also possible to compute steady-state commercial offtake which is characterized by equilibrium situation whereby 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 change in sheep flock size and structure. For steady-state situation since λ is equal to 1, the sheep flock projection model given in equation (12) is modified as:

$$\boldsymbol{n}_t = n_0 * w \tag{14}$$

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 rate is a constant while the sheep flock 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 sheep population to stable size and structure. This is important particularly when there is a need to limit the size of the sheep population due to the need to match 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 sheep flock growth dynamics is to determine what stages and what demographic rates are most likely causing the increase or decrease in the sheep flock. 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 impacts of changes in sheep demographic factors (reproductive rates and mortality rates) on long-term sheep 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. 2000):

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

Where v is the left eigenvector associated with A, and $\langle w, v \rangle$ 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 a small intervention could have a large impact in sheep 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 (de Kroon et al. 2000):

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

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. 2000).

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 corresponds to the individual stage, the elasticity values across the rows can be summed to assess how the different stages in sheep production contribute to the sheep 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 sheep 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 flock 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 sheep flock only.

The sheep flock projection model used here allows to estimate various outputs from the sheep production over time: commercial offtake of live sheep (and its meat equivalents), milk and manure production by different classes of goat, flock sizes and production systems. In order to measure the productivity, feed requirements and output, the special case of a steady state (or zero growth rate) flock, achieved by adjustment of the offtake rates is used. This is particularly important to obtain an unbiased estimate of the impacts of interventions. The steady-state is obtained by 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 commercial offtake rates numerically.

4.2. Economic model

The economic model to analyse the financial and economic profitability of sheep 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 sheep production 'without' intervention is assessed by sheep flock size classes and production systems using the present value (*PV*) of annual gross margins (*GM*) generated from sheep 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, or manure depending on the sheep production system considered) generated from sheep enterprise and variable costs (VC_t) associated with sheep production for a stable sheep flock size and structure. The major variable costs include: costs of veterinary drugs, medicine and mineral supplements. The sheep management affects the reproduction rates and mortality rates which in turn affects the performance of sheep in different production systems by affecting the rate of sheep flock growth and potential offtakes. The flock growth model is linked to the economic model whereby the offtakes from the flock growth model are monetized.

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

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

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. The *GM* represents the return to a farm's household labour, land and capital in sheep production and is considered as a farm gate measure of the gross domestic product (*GDP*) for goat. In general, the higher the *PVGM* the better. Furthermore, if the availability of data allows, the net profit for sheep production can be obtained as the difference between the *GM* and the fixed costs. The net profit indicates the extent to which the sheep producers are earning normal or excess profits and thus reflects the level of competition and risk existing in the sheep 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 sheep production systems.

The life cycle of livestock production is different by livestock species and production systems due to the difference in the biology and objectives of production in different production systems which affect the length or time horizon of the project. In such situations, when project time horizons are different, for 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:

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

Once the *APVGM* is derived it can be combined with the geographic information system (GIS) data and sheep population data to generate the sheep *GM* at herd or household level for aggregation at different levels. The computed *GM* can be mapped by assigning it to the mapped sheep population in a given production system or for the whole country as a whole. This approach allows to assess the geographic magnitude and distribution of 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 sheep policy and investment interventions is analysed using a multi-year partial budgeting framework (Gittinger 1982). 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 a 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*), (3) internal rate of return (*IRR*) (Gittinger 1982).

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

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

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

$$NPV0 = -I_0 + \sum_{t=1}^{T} \frac{(B_t^W - B_t^{WO}) - (C_t^W - C_t^W}{(1+\delta)^t} \qquad (21)$$

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 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 net incremental benefit (*ANPV*) from 'with' policy and investment intervention for a given flock class in a given production system is given as follows:

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

Where *NPV* is the net present value of net incremental benefit and the other variables are as defined as before. The income impact of the intervention is also assed in terms of annual net incremental benefit generated per individual sheep and net incremental benefit per capita.

In addition, the benefit cost ratios (BCR_s) and the internal rate of returns (IRR_s) are also calculated for the net incremental benefit from the interventions. The *BCR* measures the total financial return for each money invested in sheep 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 fund. Based on *BCR* investment criterion, it is advisable to invest if the *BCR* is greater than one and the priority is given for the project with higher or highest *BCR*. The *BCR* is given by the following formula:

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

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 returns to the investment in the project as an interest rate. It therefore permits the comparison of the returns to investment in the current project with the returns to investment in other possible projects or to simply investing the funds in an interest-earning bank account. Then, in order to make 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 initial investment interventions. This indicates that the degree to which the return to sheep investment intervention is comparable to returns to alternative investment options elsewhere and hence competes for the available fund. Mathematically, the *IRR* is expressed as:

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

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*. The *IRR* is solved by trial and error using Microsoft Excel.

Future production–consumption balances

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

$$C_t = C_0 * (1 + \eta * \gamma)^t \quad (25)$$

Where C_t is the projected per capita sheep meat (or milk) consumption for a given year *t*; C_0 is a baseline per capita consumption of sheep meat (or milk); η is the income elasticity of demand for sheep meat (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:

$$TC_t = C_0 * (1 + \eta * \gamma)^t * POP_t \quad (26)$$

In this projection, the human population projection is based on the CSA population projection for medium variant population growth scenario. 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 (2007–13). The income elasticity estimates used in the projections of meat and milk consumptions are based on estimates by the 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 meat 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 sheep flock growth model

Baseline sheep flock size and structure

The baseline sheep flock size and structure for the LG production systems used in calibrating the sheep flock projection matrices are given in Table 1. The average sheep flock size for agro-pastoral systems is 16, while the average sheep flock size for small and medium flock size pastoral system is six and 25 heads of sheep, respectively. The structure of sheep flock is analysed at two levels: globally and by sex. Globally (combining all sexes and stages of sheep growth), the sheep flock in both agro-pastoral and pastoral production systems are dominated by female sheep. The female sheep in agro-pastoral flock accounts for 73%, while the male account for about 27% of the sheep flock. The proportion of female sheep in pastoral small size flock is 82%, while in the case of pastoral medium size flock the proportion of female sheep is 75%. In general, in terms of sheep growth stage-wise the adult sheep are dominant, while sex-wise the female sheep are dominant in the sheep flock for agro-pastoral and pastoral production systems. The age-sex structure of sheep flock in LG clearly indicates the focus of agro-pastoralists and pastoralists on reproduction.

Table 1. Baseline initial sheep flock size and structure for agro-pastoral and pastoral sheep production systems

Stage class	Agro-pastoral			Pastoral—small flock size			Pastoral—medium flock size		
	Flock size	Structure		Flock size	Structure		Flock size	Structure	
		Global	Intra-sex		Global	Intra-sex		Global	Intra-sex
Young female (Fj)	3.20	0.20	0.27	1.68	0.28	0.34	4.62	0.21	0.28
Sub-adult female (Fs)	1.44	0.09	0.12	0.54	0.09	0.11	2.42	0.11	0.15
Adult female (Fa)	7.04	0.44	0.60	2.7	0.45	0.55	9.46	0.43	0.57
Young male (Mj)	2.88	0.18	0.67	0.54	0.09	0.50	2.20	0.10	0.40
Sub-adult male (Ms)	0.64	0.04	0.15	0.06	0.01	0.06	0.88	0.04	0.16
Adult male (Ma)	0.80	0.05	0.19	0.48	0.08	0.44	2.42	0.11	0.44
Total	16			6			22		

Sheep flock demographic rates

The detailed initial stage-specific demographic rates used in calibrating the sheep flock projection matrices for agro-pastoral and pastoral production systems are given in Table 2. The sheep 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 rate is similar for male sheep and female sheep but relatively higher for younger sheep as compared to older or mature sheep. The mortality rate for the young female sheep varied from 20–21%, while for juvenile male sheep the mortality rate was 22% for all systems assessed. Due to lack of data, similar levels of 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 offtake. The observed annual fecundity rate among the reproductive adult female sheep is considered very low and varies only from 60–66%. In general, the baseline sheep flock in agro-pastoral and pastoral production systems is characterized by high mortality rate, low offtake rate and low fertility rate.

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

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)
Agro-pastoral						
Fj	0–0.5	0.5	0.20	0.00	0.80	0.00
Fs	0.5–1.5	1	0.10	0.05	0.85	0.00
Fa	1.5–4.5	5	0.05	0.03	0.92	0.60
Mj	0–0.5	0.5	0.22	0.00	0.78	0.00
Ms	0.5–1.5	1	0.15	0.20	0.65	0.00
Ma	1.5–3.5	2	0.10	0.80	0.10	0.00
Pastoral—small flock size						
Fj	0–0.5	0.5	0.21	0.00	0.79	0.00
Fs	0.5–1.5	1	0.15	0.05	0.80	0.00
Fa	1.5–6.5	5	0.10	0.03	0.87	0.63
Mj	0–0.5	0.5	0.22	0.00	0.78	0.00
Ms	0.5–1.5	1	0.15	0.20	0.65	0.00
Ma	1.5–3.5	2	0.10	0.80	0.10	0.00
Pastoral—medium flock size						
Fj	0–0.5	0.5	0.21	0.00	0.79	0.00
Fs	0.5–1.5	1	0.15	0.05	0.80	0.00
Fa	1.5–6.5	5	0.10	0.03	0.87	0.66
Mj	0–0.5	0.5	0.22	0.00	0.78	0.00
Ms	0.5–1.5	1	0.15	0.20	0.65	0.00
Ma	1.5–3.5	2	0.10	0.80	0.10	0.00

Stage-structured population projection matrices

The annual Lefkovitch stage-structured population projection matrices for agro-pastoral and pastoral sheep flocks 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 sheep flock to provide sheep flock growth dynamics over time. The parameters of population projection matrix determines whether the sheep flock is declining, held constant or growing over time. The parameters also reflect the state of livestock productivity development and affected by the changes in policy and investment interventions.

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

Stage at year t+1	Stage at year t					
	Fj	Fs	Fa	Mj	Ms	Ma
Agro-pastoral						
Fj	0.00	0.00	0.55	0.00	0.00	0.00
Fs	0.80	0.34	0.00	0.00	0.00	0.00
Fa	0.00	0.51	0.92	0.00	0.00	0.00
Mj	0.00	0.00	0.55	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.78	0.26	0.00
Ma	0.00	0.00	0.00	0.00	0.39	0.10
Pastoral—small flock size						
Fj	0.00	0.00	0.55	0.00	0.00	0.00
Fs	0.79	0.31	0.00	0.00	0.00	0.00
Fa	0.00	0.49	0.87	0.00	0.00	0.00
Mj	0.00	0.00	0.55	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	0.40	0.10
Pastoral—medium flock size						
Fj	0.00	0.00	0.57	0.00	0.00	0.00
Fs	0.79	0.33	0.00	0.00	0.00	0.00
Fa	0.00	0.47	0.87	0.00	0.00	0.00
Mj	0.00	0.00	0.57	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.78	0.27	0.00
Ma	0.00	0.00	0.00	0.00	0.38	0.10

Simulation of baseline sheep flock growth dynamics

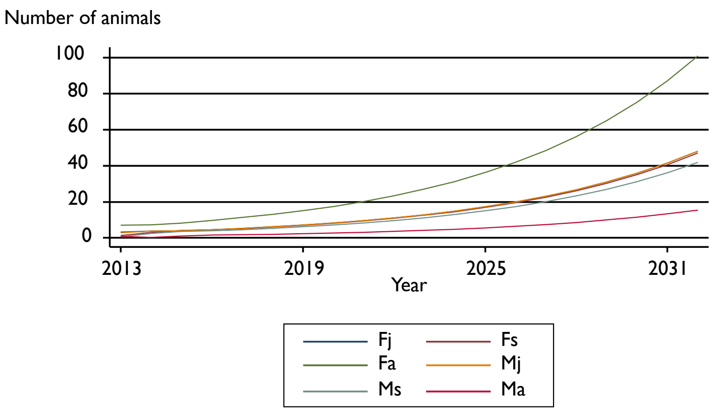
Sheep flock growth rates, stable stage distributions and stage-specific reproductive values

The baseline stable stage distribution, stage-specific reproductive values and annual long-term sheep population multiplication rates for agro-pastoral and pastoral and pastoral production systems are given in Table 4. The projected number of sheep by different classes of sheep for agro-pastoral production systems are given in Figures 1, 2, and 3. There is upward trend in the number of sheep for all sheep types and increase is especially noticeable for female adult sheep. Under the baseline scenario, the long-run sheep multiplication rate for agro-pastoral production system is 1.16 which implies a 16% sheep growth rate per year. The annual growth rate for small and medium pastoral production system is 10% and 11%, respectively. The stable stage distribution associated with this constant sheep growth rate is 16%,16%, 33%, 16%, 14% and 5% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male sheep, respectively. The stable stage distribution is also dominated by female sheep, especially adult females which accounted for 33% of sheep flock size. This might be because more adult female sheep are required to represent and maintain the flock given high mortality rate. It also observed that the adult female contributes most to the sheep reproduction followed by sub-adult female. The reproductive value of male sheep is assumed to be zero in this kind of sheep growth modelling. Similar stable stage distribution and stage-specific reproductive values are observed for both small and medium size flock pastoral production systems. For example, the adult female is small and medium pastoral sheep flock is 32% and 31%, respectively.

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

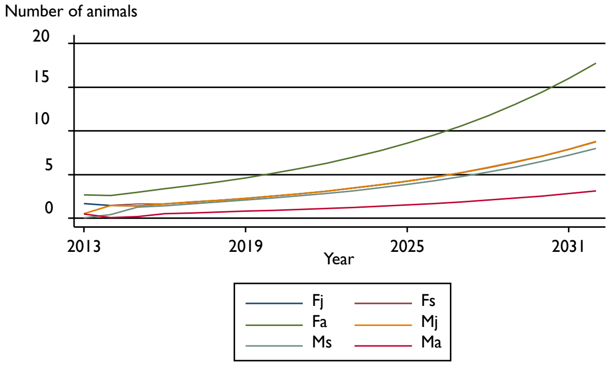
Sex-stage class	Agro-pastoral		Pastoral - small flock size		Pastoral - medium flock size	
	w	V	w	v	w	V
F_j	0.16	1.00	0.16	1.00	0.16	1.00
F_s	0.16	1.45	0.16	1.40	0.16	1.41
F_a	0.33	2.32	0.33	2.29	0.31	2.35
M_j	0.16	0.00	0.16	0.00	0.16	0.00
M_s	0.14	0.00	0.14	0.00	0.15	0.00
M_a	0.05	0.00	0.05	0.00	0.06	0.00
Λ	1.16		1.10		1.11	

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



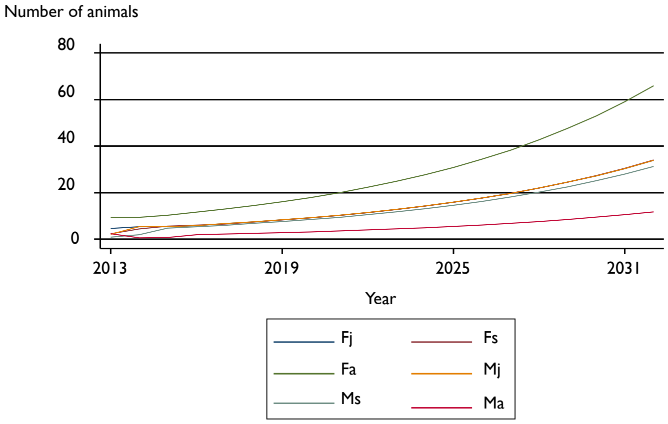
Source: Simulation results.

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



Source: Simulation results.

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



Source: Simulation results.

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 sensitivity and elasticity analyses are similar for agro-pastoral and pastoral production systems. The results of elasticity analysis shows that the long-term sheep 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 65–67% to the sheep flock growth trend. 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 survival rate results in about a 19–20% increase in the annual multiplication rate. In terms of stages of growth, it is also interesting to note that young female sheep, sub-adult and adult stage contribute 14%, 19–20%, and 65–67%, respectively, to sheep flock growth. Furthermore, it is also important to note that the female sheep fertility contributes only 14%, while the annual survivorship contributes about 86% to the sheep growth rate. Thus, under the baseline scenario, it is more important to reduce the mortality rate than improving the fertility of sheep to increase sheep growth in agro-pastoral and pastoral production systems. This indicates the importance of identifying the causes of sheep mortality and implementing cost-effective measures to reduce it. However, it should be also noted that since there is low level of sheep productivity, improving the fertility of sheep also should be addressed after mortality is improved.

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

Agro-pastoral	Sensitivity matrix			Elasticity matrix			
	Fj	Fs	Fa	Fj	Fs	Fa	Total
Fj	0.00	0.00	0.29	0.00	0.00	0.14	0.14
Fs	0.20	0.19	0.00	0.14	0.06	0.00	0.20
Fa	0.0	0.31	0.67	0.00	0.14	0.53	0.67
Total				0.14	0.20	0.67	1.01
Pastoral—small flock size							
Fj	0.00	0.00	0.29	0.00	0.00	0.14	0.14
Fs	0.20	0.20	0.00	0.14	0.05	0.00	0.19
Fa	0.00	0.32	0.66	0.00	0.14	0.52	0.66
Total				0.14	0.19	0.66	0.99
Pastoral—medium flock size							
Fj	0.00	0.00	0.28	0.00	0.00	0.14	0.14
Fs	0.20	0.20	0.00	0.14	0.06	0.00	0.20
Fa	0.00	0.34	0.65	0.00	0.14	0.51	0.65
Total				0.14	0.20	0.65	0.99

Simulation of steady state sheep flock 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 agro-pastoral and pastoral production systems are given in Table 6. Under steady state the sheep growth rate is zero in that the sheep flock size is kept constant at the initial level. The expected changes are, therefore, in terms of stable stage distribution and offtake rates as compared to the initial sheep flock structure.

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

Stage class	Agro-pastoral			Pastoral—small flock size			Pastoral—medium flock size		
	W	v	Offtake rate	W	V	Offtake rate	W	V	Offtake rate
Fj	0.14	1.00	0.00	0.15	1.00	0.00	0.15	1.00	0.00
Fs	0.17	1.22	0.18	0.17	1.23	0.14	0.17	1.28	0.15
Fa	0.31	1.92	0.20	0.31	2.00	0.16	0.30	2.04	0.17
Mj	0.14	0.00	0.00	0.15	0.00	0.00	0.15	0.00	0.00
Ms	0.16	0.00	0.20	0.16	0.00	0.20	0.16	0.00	0.20
Ma	0.07	0.00	0.80	0.07	0.00	0.80	0.07	0.00	0.80

The steady state sheep production is obtained by numerically adjusting the offtake rates by sex and stage of sheep growth. The sheep population is growing under the baseline scenario and therefore in order to obtain steady state sheep production there is a need to decrease the sheep flock size by decreasing the sheep types (sex and stage) which significantly contribute to sheep growth. Thus, a zero sheep growth rate is obtained by increasing the offtake of female sheep mainly sub-adults and adult females. As a result, under steady state the percentage offtake of sub-adult female sheep has substantially increased. For example, in the case of agro-pastoral and pastoral flock, the offtake rates for sub-adult and adult female sheep increased from 5% and 3% in the baseline situation to 17% and 31%, respectively. The male offtake rates remained constant as males do not contribute to long-term sheep growth. In general, the observed baseline offtake rate is below the steady state offtake rate which indicates an suboptimal offtake strategy practiced by livestock keepers. The reason for this practice needs to be investigated. Similar results are observed for pastoral sheep production systems. For example, in the case of pastoral production flocks the observed baseline offtake rate for adult female sheep is 3% while the steady state offtake rate is 16.5%.

Sheep meat production

The annual steady state net live sheep offtake and equivalent carcass meat production (total carcass weight in kg) by different sheep production systems is given in Table 7. The average net offtake varied from 16–18% for agro-pastoral and pastoral production systems. For the agro-pastoral sheep flock the average annual sheep meat production per sheep flock is 32 kg which is about two live sheep equivalents. The highest annual average sheep offtake of 41 kg is obtained for the medium size pastoral sheep production system.

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

Production system	Average net offtake rate (%)	Average annual sheep meat production (kg/flock)1	Annualized present value per sheep flock (ETB)	Annualized present value per head of sheep (ETB/head)
Agro-pastoral	0.18	32	2476	155
Pastoral small flock size	0.16	12	861	143
Pastoral medium flock size	0.17	41	2920	133

Note: [1]The time horizon for the projection is 20 years. [2]The annual sheep production is in carcass equivalent weight assuming 45 to 50% dressing percentage.

Financial profitability of sheep production

The results of the analysis of financial profitability of sheep production at steady state is given in Table 7. The income from sheep production is derived from the sale of live sheep and imputed values of manure used in crop production. The annualized present values of gross margin (*GM*) for sheep outputs per flock and per head of sheep are given in Table 7. The annualized present value of *GM* per sheep flock for agro-pastoral and pastoral small flock and medium flock size is ETB2476, ETB861 and ETB2920, respectively. The annualized present value of sheep output per head of sheep is also computed and found to be ETB155 for the agro-pastoral flock while for the small and medium size pastoral flocks is ETB143 and ETB133, respectively. In general, given the demographic factors, herd size and structure, the results show that there is limited annual live sheep offtake.

Mixed rainfed moisture deficient (MRD) crop–livestock production system

Parameterization of sheep flock growth model

Baseline sheep flock size and structure

The baseline or initial sheep flock size and structure for the MRD production system used in calibrating the sheep flock projection matrices is given in Table 8. The observed sheep flock sizes are very small for the MRD. The average sheep flock size for small flock MRD is three, while the average sheep flock size for medium MRD is 11 heads of sheep. The structure of the sheep flock is analysed at two levels: globally and by sex. Female sheep in small flock size accounts for 72%, while males account for about 28%. In in the case of medium flock, the proportion of female sheep flock is 73. Similar to the agro-pastoral and pastoral production system, the female adult sheep are dominant classes of sheep for the MRD production system. The sex and age structure of the flock indicate the importance of attached to the reproduction in sheep production.

Table 8. Baseline initial sheep flock size and structure for the MRD sheep production system

Stage class	Small flock size			Medium flock size		
	Flock size	Structure		Flock size	Structure	
		Global	Intra-sex		Global	Intra-sex
Young female (Fj)	0.54	0.18	0.25	2.20	0.20	0.27
Sub-adult female (Fs)	0.36	0.12	0.17	0.99	0.09	0.12
Adult female (Fa)	1.26	0.42	0.58	4.84	0.44	0.60
Young male (Mj)	0.54	0.18	0.64	1.76	0.16	0.62
Sub-adult male (Ms)	0.15	0.05	0.18	0.33	0.03	0.12
Adult male (Ma)	0.15	0.05	0.18	0.77	0.07	0.27
Total	3			11		

Sheep flock demographic rates

The detailed initial sex-age stage-specific demographic rates used in calibrating sheep flock projection matrices for the MRD production system are given in Table 9. The sheep demographic rates varied by sex, stage of growth and production system. It is interesting to note that the observed mortality rates are higher for younger sheep as compared to older or mature sheep. Due to lack of data, similar levels of commercial offtake rates are assumed for all MRD production systems. The initial assumed annual survivorship rate is also similar across different production systems because of the assumed similar levels of annual mortality rates and annual commercial offtake rates. The observed annual fecundity rate among the reproductive female sheep is considered to be very low and estimated at about 71% and 75% for small flock and medium flock, respectively.

Table 9. Stage specific demographic rates used in calibrating sheep flock projection matrices for the MRD 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 flock size						
Fj	0–0.5	0.5	0.16	0.00	0.84	0.00
Fs	0.5–1.3	0.8	0.09	0.10	0.81	0.00
Fa	1.3–7.3	6	0.10	0.20	0.70	0.71
Mj	0–0.5	0.5	0.23	0.00	0.77	0.00
Ms	0.5–1.3	0.8	0.09	0.10	0.81	0.00
Ma	1.3–3.8	2.5	0.10	0.80	0.10	0.00
Medium flock size						
Fj	0–0.5	0.5	0.16	0.00	0.84	0.00
Fs	0.5–1.3	0.8	0.09	0.10	0.81	0.00
Fa	1.3–7.3	6	0.10	0.20	0.70	0.00
Mj	0–0.5	0.5	0.23	0.00	0.77	0.75
Ms	0.5–1.3	0.8	0.09	0.10	0.81	0.00
Ma	1.3–3.8	2.5	0.10	0.80	0.10	0.00

Stage-structured population projection matrices

The annual Lefkovitch stage-structured population projection matrices for agro-pastoral and pastoral sheep flocks 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 sheep flock to provide sheep flock growth dynamics over time. The parameters of population projection matrix determine whether the sheep flock is declining, held constant or growing over time. The parameters also reflect the state of livestock productivity development and how it is affected by the changes in policy and investment interventions.

Table 10. Lefkovitch sex-structured population projection matrices for MRD sheep flock

Stage at year t+1	Stage at year t					
	Fj	Fs	Fa	Mj	Ms	Ma
Small flock size						
Fj	0.00	0.00	0.50	0.00	0.00	0.00
Fs	0.84	0.43	0.00	0.00	0.00	0.00
Fa	0.00	0.38	0.70	0.00	0.00	0.00
Mj	0.00	0.00	0.50	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.77	0.43	0.00
Ma	0.00	0.00	0.00	0.00	0.38	0.10
Medium flock size						
Fj	0.00	0.00	0.52	0.00	0.00	0.00
Fs	0.84	0.43	0.00	0.00	0.00	0.00
Fa	0.00	0.38	0.70	0.00	0.00	0.00
Mj	0.00	0.00	0.52	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.77	0.43	0.00
Ma	0.00	0.00	0.00	0.00	0.38	0.10

Simulation of baseline sheep flock growth dynamics

Sheep flock growth rates, stable stage distributions and stage-specific reproductive values

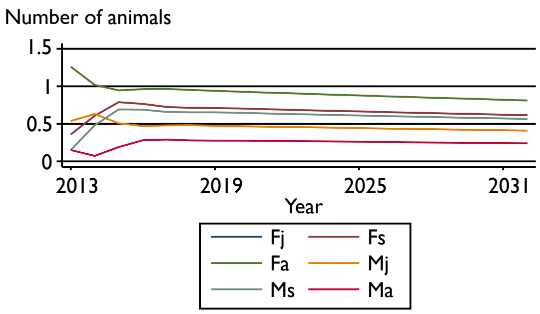
The baseline stable stage distribution, stage-specific reproductive values and annual long-term sheep population multiplication rates for the MRD production system are given in Table 11. The projection of the number of animals for different classes of sheep for small flock and medium flock are given in Figure 4 and Figure 5, respectively. It is observed that under the baseline scenario, the long-run sheep multiplication rate for the small and medium MRD production system is 1.00 and 0.92, respectively, which imply annual growth rate of 0% and -8%, respectively, in sheep flock size. Thus, the sheep flock in the MRD system is either stable or declining in the long-run.

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

Stage class	Small flock size		Medium flock size	
	w	V	w	V
Fj	0.13	1.00	0.12	1.00
Fs	0.20	1.18	0.11	1.10
Fa	0.26	1.73	0.21	2.36
Mj	0.13	0.00	0.17	0.00
Ms	0.18	0.00	0.12	0.00
Ma	0.08	0.00	0.12	0.00
Λ	1.00		0.92	

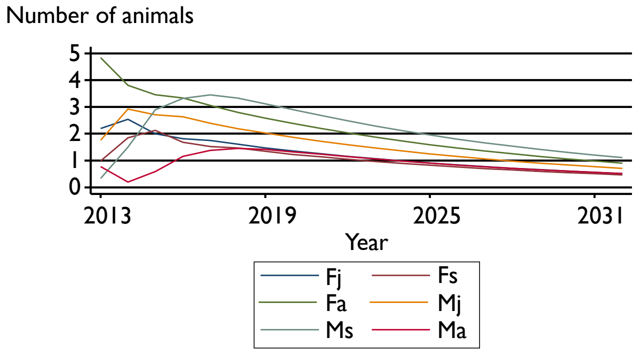
For small sheep flock size, the stable stage distribution associated with this constant sheep growth rate is 13%, 20%, 26%, 13%, 18% and 8% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male sheep, respectively. Similar to initial stage structure, the stable stage distribution is also dominated by adult females. It is also observed that the adult females contribute most to the sheep reproduction followed by sub-adult females. Similar stable stage distribution and stage-specific reproductive values are observed for the medium size flock MRD production system. For the medium size sheep flock, the stable stage distribution is also dominated by female sheep which accounts for 44% of sheep flock size.

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



Source: Simulation results.

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



Source: Simulation results.

Sensitivity and elasticity analysis

The results of sensitivity and elasticity analyses for MRD sheep production systems are given in Table 12. Similar to agro-pastoral and pastoral production systems, the elasticity analysis shows that the long-term sheep population growth rate is most elastic to the probability that an adult female survives and persists as an adult. In the case of small flock size sheep, the adult female survival contributes about 39% to the sheep flock 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 survival rate results in about 28% increase in annual multiplication rate. In terms of stages of growth, it is also interesting to note that young female sheep, sub-adult and adult stage contribute 16%, 28% and 55%, respectively, to sheep flock growth. Furthermore, it is also important to note that the female sheep fertility contributes, only 16% while the annual survival rate contributes about 83% to the sheep flock growth rate. Thus, in the case of small flock size sheep under the baseline scenario, it is more important to reduce mortality rate than improving the fertility rate of sheep in order to increase sheep growth in MRD production systems. The results of sensitivity and elasticity analyses for medium size flock size sheep are similar to that of the small size sheep flock.

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

	Sensitivity matrix			Elasticity matrix			
	Fj	Fs	Fa	Fj	Fs	Fa	Total
Small flock size							
Fj	0.00	0.00	0.32	0.00	0.00	0.16	0.16
Fs	0.19	0.28	0.00	0.16	0.12	0.00	0.28
Fa	0.00	0.42	0.55	0.00	0.16	0.39	0.55
Total				0.16	0.28	0.55	0.99
Medium flock size							
Fj	0.00	0.00	0.28	0.00	0.00	0.16	0.16
Fs	0.18	0.00	0.00	0.16	0.00	0.00	0.16
Fa	0.00	0.35	0.67	0.00	0.16	0.51	0.67
Total				0.16	0.16	0.67	0.99

Simulation of steady state sheep flock 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 the MRD sheep production systems are given in Table 13. The steady state sheep production is obtained by numerically adjusting the commercial offtake rates by sex and stage of sheep growth. It is to be recalled that the sheep population is already stable under the baseline scenario in the case of the small flock size sheep and therefore in order to obtain steady state sheep production there is no need to decrease or increase the sheep flock size. However, in the case of the medium flock size sheep, the sheep population is declining and therefore in order to obtain steady state sheep production there is a need to increase the sheep flock size by increasing the sheep classes (sex and stage) which significantly contributes to sheep growth. Thus, the zero sheep growth rate characterizing the steady state is obtained by decreasing the commercial offtake of female sheep mainly sub-adult and adult female goat.

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

Stage class	Small flock size			Medium flock size		
	w	v	Offtake rate	w	V	Offtake rate
Fj	0.13	1.00	0.00	0.13	1.00	0.00
Fs	0.20	1.15	0.10	0.21	1.19	0.10
Fa	0.26	1.63	0.23	0.26	1.78	0.20
Mj	0.13	0.00	0.00	0.13	0.00	0.00
Ms	0.19	0.00	0.10	0.19	0.00	0.10
Ma	0.08	0.00	0.80	0.08	0.00	0.80

Sheep meat production

The annual steady state sheep meat production (total carcass weight) by different sheep production system is given in Table 14. The average live sheep net offtake rate varied from 16–17%. For small sheep flock the average annual sheep meat production per sheep flock is 5 kg, slightly less than one live sheep equivalent. The average annual sheep meat production for medium flock size sheep is 20 kg, slightly more than one live sheep equivalent.

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

Production system	Average net offtake rate (%)	Average annual sheep meat production (kg/flock)[2]	Annualized present value of *GM* per sheep flock (ETB)	Annualized present value of *GM* per head of sheep (ETB/head)
MRD				
Small flock size	0.16	5	522	174
Medium flock size	0.17	20	1794	163

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

Financial profitability of sheep production

The results of the analysis of financial probability of sheep production at steady state are given in Table 14. The annualized present value of gross margin (*GM*) for sheep production per head of sheep is given in Table 14. The average annualized present value of *GM* per sheep flock is ETB522 /flock and ETB1794/flock for the small and medium flock size sheep, respectively. The annualized present value of sheep output per head for small sheep flock MRD is estimated to be ETB174. In the case of the medium MRD, the annualized present value of *GM* for sheep outputs per head of sheep is ETB163. The small flock size sheep is relatively more productive.

Mixed rainfed moisture sufficient (MRS) crop–livestock production system

Parameterization of sheep flock growth model

Baseline sheep flock size and structure

The baseline initial sheep flock size and structure for MRS production system used in calibrating the sheep flock projection matrix is given in Table 15. The average sheep flock size for MRS is five. Globally, female sheep accounts for 73%, while the male account for about 28% of the sheep flock. Within female sheep flock, the adult female sheep are dominant (58%), while within the male sheep flock, the young sheep are dominant (77%).

Table 15. Baseline initial sheep flock size and structure for the MRS sheep production system

Stage class	Small flock size		
	Flock size	Structure Global	Intra-sex
Fj	1.00	0.20	0.28
Fs	0.50	0.10	0.14
Fa	2.10	0.43	0.58
Mj	1.00	0.20	0.77
Ms	0.15	0.03	0.12
Ma	0.15	0.03	0.12
Total	5		

Sheep flock demographic rates

The detailed initial stage-specific demographic rates used in calibrating sheep flock projection matrix for the MRS production system are given in Table 16. The sheep demographic rates varied by sex and stage of growth. In general, there is high sheep mortality rate in the MRS production system. Particularly, it is important to note that the young sheep mortality rate (26%) is higher than that of adult sheep for both sex. The observed annual fecundity rate among the reproductive female sheep is considered very low and estimated at about 75%.

Table 16. Stage specific demographic rates used in calibrating sheep flock projection matrices for the MRS sheep 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 rate (F)
Small flock size						
Fj	0–0.5	0.5	0.26	0.00	0.74	0.00
Fs	0.5–1.3	0.8	0.10	0.10	0.80	0.00
Fa	1.3–7.3	6	0.08	0.10	0.82	0.75
Mj	0–0.5	0.5	0.26	0.00	0.74	0.00
Ms	0.5–1.3	0.8	0.10	0.10	0.80	0.00
Ma	1.3–3.8	2.5	0.09	0.80	0.11	0.00

Stage-structured population projection matrices

The annual Lefkovitch stage-structured population projection matrix for agro-pastoral and pastoral sheep flocks 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 sheep flock to provide sheep flock growth dynamics over time. The parameters of population projection matrix determines whether the sheep flock is declining, held constant or growing over time. The parameters also reflect the state of livestock productivity development and are affected by the changes in policy and investment interventions.

Table 17. Annual Lefkovitch stage-structured population projection matrices for the sheep flock MRS production system

Stage at year t+1	Stage at year t					
	Fj	Fs	Fa	Mj	Ms	Ma
Small flock size						
Fj	0.00	0.00	0.61	0.00	0.00	0.00
Fs	0.74	0.42	0.00	0.00	0.00	0.00
Fa	0.00	0.38	0.82	0.00	0.00	0.00
Mj	0.00	0.00	0.61	0.00	0.00	0.00
Ms	0.00	0.00	0.00	0.74	0.42	0.00
Ma	0.00	0.00	0.00	0.00	0.38	0.11

Simulation of baseline sheep flock growth dynamics

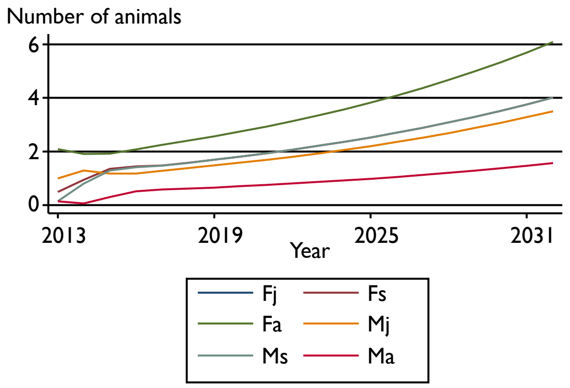
Sheep flock growth rates, stable stage distributions and stage-specific reproductive values

The baseline stable stage distribution, stage-specific reproductive values and annual long-term sheep population multiplication rates for the MRS production system are given in Table 18. The projection of livestock numbers for different classes of sheep in the MRS production system are given in Figures 6. There is upward trend for all sheep types in the MRS. It is observed that under the baseline scenario, the long-run sheep multiplication rate for the MRS production system is 1.07 which implies a 7% sheep growth rate per year. The stable stage distribution associated with this constant sheep growth rate is 15%, 18%, 27%, 15%, 18% and 7% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male sheep, respectively. The stable stage distribution is also dominated by female sheep, especially adult females which accounts for 27% of sheep flock size. It is also observed that the adult female contributes most to the sheep reproductive value followed by sub-adult female. The reproductive value of male sheep is assumed to be zero in this kind of sheep growth modelling.

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

Stage-Class	Parameter	V
	W	
Fj	0.15	1.00
Fs	0.18	1.44
Fa	0.27	2.47
Mj	0.15	0.00
Ms	0.18	0.00
Ma	0.07	0.00
Λ	1.07	

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



Source: Simulation results.

Sensitivity and elasticity analysis

The results of sensitivity and elasticity analyses for MRS production systems are given in Table 19. The results of elasticity analyses show that the long-term sheep population growth rate is most elastic to the probability that an adult female survives and persists as an adult. The adult female contributes about 47% to the sheep flock growth in the 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 sheep in the MRS production system results in about 23% increase in annual multiplication rate. In terms of stages of growth, it is also interesting to note that young female sheep, sub-adult and adult stage contribute 14%, 23%, and 61%, respectively, to sheep flock growth in the small flock MRS production system. Furthermore, it is also important to note that female sheep fertility contributes only 14%, while the annual survivorship contributes about 86% to the sheep growth rate. Thus, similar to other sheep production systems, under the baseline scenario, it is more important to reduce mortality rate than improving the fertility of sheep to increase sheep growth in the MRS production system.

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

	Sensitivity matrix			Elasticity matrix			
	Fj	Fs	Fa	Fj	Fs	Fa	Total
Small flock size							
Fj	0.00	0.00	0.25	0.00	0.00	0.14	0.14
Fs	0.21	0.24	0.00	0.14	0.09	0.00	0.23
Fa	0.00	0.41	0.62	0.00	0.14	0.47	0.61
Total				0.14	0.23	0.61	0.98

Simulation of steady state sheep flock 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 sheep production is obtained by numerically adjusting the commercial offtake rates by sex and stage of sheep growth. This indicates that in order to obtain steady state sheep production there is a need to decrease the sheep flock size by decreasing certain types of sheep which significantly contribute to sheep growth. Thus, the zero sheep growth rate is obtained by increasing the commercial offtake of female sheep mainly adult female goats. As a result, under steady state the percentage offtake of adult female sheep substantially increased, from 10% in the baseline to 23% in the steady state.

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

Sex-stage class	Small flock size		
	W	V	Offtake rate
Fj	0.14	1.00	0.02
Fs	0.19	1.29	0.13
Fa	0.26	1.95	0.23
Mj	0.14	0.00	0.00
Ms	0.19	0.00	0.10
Ma	0.09	0.00	0.80

Sheep meat production

The annual steady state sheep meat production (total carcass weight) for the MRS sheep production system is given in Table 21. The average annual sheep production per sheep flock is 8 kg, about one live sheep equivalent. The average annual offtake rate for the sheep flock as a whole is 17%.

Financial profitability of sheep production

The results of the analysis of financial probability of sheep meat production at steady state is given in Table 21. The annualized present value of *GM* for sheep production per flock and per head of sheep are given in Table 21. The annualized present value of sheep outputs per flock of sheep for the MRS sheep flock is estimated to be ETB825. On the other hand, the annualized present value of *GM* per head of sheep is ETB165.

Table 21. Steady state sheep meat production and annualized present value of gross margin for moisture sufficient sheep production system in Ethiopia[1]

Production system	Average net offtake rate (%)	Average annual sheep meat production (kg/flock)[2]	Annualized present value of gross margin (ETB)	Annualized present value of per head of sheep (ETB/head)
MRS				
Medium flock size	0.17	8	825	165

Note: [1]The time horizon for the projection is 20 years. [2]The annual sheep meat production is in carcass equivalent weight assuming 45 to 50% dressing percentage.

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

Description of bio-economic simulation analysis

Introduction

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

First, for the poor livestock producers, who survive on just a few animals as a source of food, income, means of production and main productive asset, the death of animals due to disease has a 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, livestock mortality and productivity loss 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 since it limits access to international markets. Finally, the livestock diseases affect not only livestock farms and the livestock industries but also sectors outside of farming. 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 animal health interventions are needed to reduce the negative impacts of livestock diseases and parasites on household and national economy. The high incidence of disease and mortality indicate the lack of adequate investment in animal health and management practices. However, the funds available for various interventions are also limited which requires *ex-ante* 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 discussed in section 4 is applied to analyse *ex-ante* the impacts of combined animal health and feed management interventions in sheep production in different production systems.

Description of bio-economic simulation of sheep health interventions

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 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 investment. 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 the rationalization of public and private veterinary sector services, and improvements in feeding and management practices (e.g. supplemental practices like mineral supplements). The specific actions required are the creation 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; a gradual decrease in subsidies given in public veterinary clinics (on services and drugs); and the provision of incentives (credit and subsidies) for the establishment of private veterinary clinics in remote areas and by young veterinarians in all areas. The policy investment interventions are expected to result in the 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 sheep population currently reached by veterinary health service is 30% and the percentage of the animal population at risk that are targeted by the interventions are 70% of the population. From experience, the adoption rate for interventions is assumed to progress slowly. The adoption rate is expected to reach 20% by the fifth year of the project; 40% by the tenth year; 80% by the fiftieth 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 the 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 ETB1 billion to be equally spent over three years to improve animal health, feeding and management. 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 (lowland grazing system, highland mixed rain deficient system and mixed rain sufficient system). 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 FMD for sheep is assumed to cost ETB5/dose and two doses per head/year or ETB10 per head/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
Foot-and-mouth disease (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

The vaccination cost required for animal export diseases of trade, such as PPR, CBPP, CCPP, etc. is estimated at an unsubsidized cost of ETB7/head per year for sheep. Sheep will be also treated against internal and external parasites. The treatment against internal and external parasite is assumed to be ETB6/head for sheep. The vaccination service charge is assumed to be ETB1/head on average. The additional cost for improved veterinary service per head is ETB2 for sheep.

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 ETB0.5 /head for sheep. 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 ETB0.5/head for sheep to achieve improved management in animal feeding, housing and better sanitation. The total investment cost per animal affected per year for vaccination and anti-parasitic drug is estimated at ETB25/head for sheep.

Description of bio-economic simulation of sheep feeding interventions

To realize the impact of animal health interventions, there have to be also complementary improvements in the animal feeding and management practices and is discussed next. The adequate feeding of the pregnant animal at its late stage of pregnancy and early stage of lactation by providing more concentrates is suggested. This is assumed to cost about ETB3/kg for sheep. The amount of concentrates recommended varies by class of animal. There is no feed purchase for sheep, but it is assumed that improved feed available on-farm will result in daily incremental weight gain of 12 grams.

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 sheep sub-sector are analysed *ex ante* at different levels: at household or flock level, typology of livestock production zones level and national level. The *ex-ante* financial profitability of sheep 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 sheep production. For this purpose, the household level partial budgets, the building blocks for *ex ante* financial analysis, were constructed for different flock sizes by different production systems and then the projected cash flows are 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 sheep 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 in sheep production is assessed *ex-ante* in terms of closing the rapidly growing production–consumption gap and generating surpluses of live sheep meat 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 sheep research and development (policies and technologies), which will be required to close the production–consumption gap in sheep meat production. Considering a 15-year projection period (2013-28), the results for sheep meat is presented in Tables 23.

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

Status of intervention	National production	National consumption	Production–consumption balance (103 tonnes) +	Production as a percent of consumption (%)
	(103 tonnes)	(103 tonnes)		
Without	348	183	165	191
With	390	183	208	214

Note $^{+}$ negative values indicate deficits while positive values indicate surpluses. The sheep meat is measured in terms of carcass equivalent of net live sheep offtake.

Under the 'without' intervention scenario, the projected total production of sheep meat in 2028 is about 348 thousand metric tonnes. The projected total consumption of sheep meat is estimated at 183 thousand metric tonnes, so the domestic production will be sufficient to meet the projected consumption requirements. Thus, the projected self-sufficiency rate for sheep meat without intervention in 2028 is about 191%. There will be a sheep meat surplus of 165 thousand metric tonnes. Therefore, there is an opportunity to export surplus sheep meat and thus generate foreign exchange earnings for the country. Investment intervention further expands sheep meat production, increasing the surplus sheep meat to 208 thousand metric tonnes. So the challenge for sheep meat is to find export markets which absorb the surplus created and to meet the required quality requirements at competitive prices.

Impacts on financial profitability

The results of the *ex-ante* financial profitability of the combined investment analyses by sheep production systems in Ethiopia are given in Table 24. 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 one in all cases except for small flock size LG. However, it is observed that the returns to sheep investment interventions differ by sheep production systems. By far the highest *IRR* is observed for MRS production system while the lowest *IRR* is observed for LG production system which shows the extensive nature of livestock production system in the LG system. In general, all the financial performance criteria used indicate the financial viability of combined sheep policy and investment interventions in most of the sheep production systems in Ethiopia, except for small LG. It is important to note that there are also several social and cultural benefits of sheep 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 sheep production might be underestimated.

Table 24. Returns to combined policy and investment interventions in cattle production by sheep production systems in Ethiopia (2013–32)

Sheep production system	Flock size group	Indicators of return to investment*		
		NPV (106 ETB)	*IRR* (%)	*BCR*
MRS	Small	1483	37	2.96
MRD	Small	448	30	2.29
	Medium	1684	30	2.13
LG	Small	-823	-6	0.4
	Medium	26	11	1.0
	Large	1074	18	1.3

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

Impacts on household income

In order to assess the household level income and poverty impacts of sheep policy and investment interventions, the 20-years incremental benefits and costs from combined policy and investment interventions were annualized assuming a discount rate of 10%. The results are presented in Table 25. Five performance measures were derived: annual incremental benefits per flock, annual incremental costs per flock, annual net incremental benefits per flock, annual net incremental benefits per head of goat, and annual net 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 for 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 sheep is obtained by dividing the annual incremental net benefit per flock by average sheep flock size. This measures the relative profitability of sheep in different production systems. The annual net incremental per capita income is obtained by dividing the annual net incremental benefit per flock by average family size of 4.7 people. The results are presented by sheep production system and sheep flock size classes.

Table 25. Summary of discounted benefits and costs due to combined investment interventions in sheep production by production system in Ethiopia

Sheep production system	Flock size group	Annual incremental benefits (ETB/Flock)	Annual incremental costs (ETB/Flock)	Annual incremental net benefit (ETB/Flock)	Annual net incremental benefit per head (ETB)	Annual net incremental per capita income (ETB)
MRS	Medium (5)*	263	89	174	29	37
MRD	Small (3)	92	40	52	17	11
	Medium (11)	373	175	198	18	42
LG	Small (16)	70	167	-97	-6	-21
	Medium (6)	101	98	3	0.5	0.61
	Large (22)	529	403	126	6	27

Note: * The figures in parenthesis indicate the sheep flock size.

The income impact of combined investment intervention in sheep production is different by sheep production system and sheep flock size classes. The highest incremental net benefit of ETB313/flock is obtained for the medium size pastoral sheep flock followed by agro-pastoral sheep flock. Within each production system, it has also been observed that the higher the sheep flock size, the higher the incremental net benefit of the investment intervention. This result indicates the importance of the production system in which sheep are raised and the sheep flock size in influencing the return to sheep investment. In general, the *ex-ante* assessment indicates that combined policy and investment interventions in sheep production substantially enhance the returns to sheep production under different production systems. It has also been observed that larger sheep flock sizes are more productive in all production systems and indicates the importance of increasing sheep flock size in raising sheep productivity.

6. Conclusions and policy recommendations

The objective of this paper is to present an analytical and empirical modelling framework which integrates sheep flock growth with an economic model for simulating the impacts of improvements in sheep production. The modelling framework allows for the *ex-ante* assessment of the technical and financial performance of sheep production 'without' and 'with' investment interventions. The data on sheep size and flock structure, demographic parameters and financial parameters used in the bio-economic simulation model were obtained from secondary sources based on literature review, opinions, national and international livestock experts and analysis of cross-sectional household survey data from secondary sources.

The baseline assessment of the sheep production systems indicate that the sheep sub-sector is characterized by high mortality rates, low fertility and low offtake rates, thus contributing to low productivity levels. The average sheep flock size observed is very small, particularly in the mixed crop–livestock production systems. Bio-economic simulation of baseline situation indicates that sheep production in the agro-pastoral and pastoral different production systems is growing at annual growth rate of 10–16%, while in the case of the MRD it is either stable or declining, and in the case of the MRS it is growing at 7% per annum. The baseline assessment also indicates that adult female sheep are the most important class of sheep explaining the various future sheep population growth trajectories.

The observed low flock size and low levels of productivity indicate the potential of increased returns from investing in sheep genetic improvement, health, reproductive management and nutrition. Particularly, the results of sensitivity and elasticity analyses indicate that female sheep fertility contributes only about 15%, while the annual survival of female sheep contributes about 85% to the sheep flock growth rate. Thus, it is more important to reduce the mortality rate than improving the fertility of sheep to increase sheep flock growth in the different production systems. This indicates the importance of identifying the causes of sheep mortality and implementing cost-effective measures to reduce it. The small flock size also indicates the need to increase flock size. This requires detailed *ex-ante* benefit–cost analysis of various interventions using the bio-economic simulation model outlined in this paper are required. Here, the bio-economic simulation model is applied to assess *ex-ante* the impacts of the proposed combined investment interventions to reduce young and adult stock mortality in sheep.

The results of bio-economic simulation analysis indicate that the combined investment interventions in sheep health, feeding and management practices to reduce sheep young stock and adult stock mortality is financially viable except for small flock size sheep in the LG. The investment enhances Ethiopia's sheep meat self-sufficiency ratio and has a significant impact on sheep keepers' income. However, the implementation of the proposed combined investment interventions will require strong private and public partnerships and involve the rationalization and improvement of public and private sector veterinary service provisions and public investments. Some of the key policy recommendations are:

- Improvements in goat producers' access to quality feed at reasonable price;
- Improvements in goat extension and advisory services;
- Improvements in access to livestock markets and information;

- Improvements in access to financial services;
- Improvements in goat 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 creation 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;
- A gradual decrease in subsidies given in public veterinary clinics (on services and drugs);
- The provision of incentives (credit and subsidies) for the establishment of private veterinary clinics in remote areas and by young veterinarians in all areas;
- The adoption of new technologies, such as the use of anti-parasitic control drugs and vaccinations, for transboundary animal and other diseases;
- The rationalization 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;
    - A gradual withdrawal of the public sector from clinical services;
    - The establishment of sanitary mandate—delegation of certain public good activities to the private sector; and
    - The provision of loans for interested private service providers.

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