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Transforming traditional smallholder cow milk production systems in Ethiopia: Ex-ante evaluation

Transforming traditional smallholder cow milk production systems in Ethiopia: *Ex-ante* evaluation

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Contents

Tables

Figures

1. Introduction

1.1 Background and justification

In the context of developing countries like Ethiopia, the potential economic and social advantages of market-oriented smallholder dairying in improving the livelihoods of farm households and its multiplier effects on other sectors of the economy are well known (Walshe *et al.* 1991; Hemme *et al.* 2003; Bennet *et al.* 2006). First, it generates income for the farm households on a regular basis which can be used for different purposes, e.g. purchase of goods for household consumption, payment of school fees and medical expenses. Income generated from the sale of milk can also be used for financing productive investments in other farm or non-farm activities. Second, milk from dairy production provides a highly nutritious food for people of all age groups, particularly for infants and lactating mothers, thus reducing the problem of malnutrition among rural and urban households. Third, value adding activities, such as the processing, marketing and distribution of dairy and dairy products create employment opportunities in rural and urban areas. It is also argued that in situations where the arable land is shrinking and where there is high population density, dairy farming may be one of the few agricultural activities that can support viable smallholder farming (Staal *et al.* 1997). There are also several other intermediate products attached to livestock ownership and production, such as organic fertilizer (manure) for crop production, and socioeconomic functions such as storage of wealth, risk mitigation, and display of social status (Moll *et al.* 2007).

Meanwhile, milk consumption is growing at a rapid pace in Ethiopia; producer and consumer prices are high by international standards, making investment in dairy a potentially lucrative business opportunity. Increasing demand for dairy products can be expected to continue due to increasing urbanization, population growth, emergence and expansion of supermarkets, cafés and restaurants, and growth in western-style dietary habits requiring dairy and dairy products as major food ingredients. However, a key question is whether a smallholder farmers will be able to seize these emerging market opportunities given their current production and marketing methods.

The agro-ecology of Ethiopia is also very conducive to dairy production and milk is produced in all livestock producing areas: lowland grazing (LG) system, and moisture deficient (MRD) and moisture sufficient (MRS) mixed crop livestock production systems, as well as in specialized commercial dairy units (SP). Approximately 77% of the milk produced in Ethiopia comes from cows, while 20% comes from camels and 3% from goats (Livestock Sector Analysis (LSA) results). The majority of marketed dairy products also come from cow milk that has been processed into butter or cottage cheese—*ayib* (46% of the total production). Liquid milk is sold raw or pasteurized and transformed into other dairy products—54% (LSA results). Relatively large quantities of camel milk are also marketed and exported, (reportedly 100,000 litres /day), while most goat milk is consumed at household level. Due to the availability of proven technologies aimed at improving the productivity of dairy cows and the large scope for impact on producers (since there are approximately 9.5 million cattle-keeping households), cow milk has been identified as a high potential investment.

Milk production in the traditional mixed crop-livestock production system is based on three–five low productivity indigenous dairy cows, limited communal and/or private grazing areas and the use of crop residues and stubbles as major sources of dairy cows feeds. Most milk production from the smallholder production system is also processed and consumed on-farm. The milk from this system is marketed mainly through the informal markets. On the other hand, the pastoral production system is based on extensive communal grazing, while agro-pastoralists are characterized by a combination of both pastoral and mixed crop-livestock production systems.

Both the traditional pastoral and sedentary livestock production systems can be characterized as smallscale, low-input and not commercially oriented, with very little or no vertical integration. The other common features of these two cattle production systems is that livestock producers keep different livestock species for multiple uses, although milk is one of the major products obtained. Peri-urban and urban small dairy producers meanwhile rely on purchased feed inputs, improved dairy cow breeders, and are commercially oriented. Meanwhile, the modern specialized commercial dairy production system in Ethiopia is at an early stage of its development and accounts for very small amount of milk (less than 10%) produced in the country.

The current level of dairy cow productivity in Ethiopia is very low. For example, the national milk yield for an indigenous dairy cow is estimated at 1.4 litres/cow per day and has shown very little improvement over the last several years. The average national lactation length is six months. The traditional dairy cattle system is also characterized by low reproductive performance, such as long calving intervals, low conception rates and long open periods. In general, the low levels of dairy cattle productivity and reproductive performance, but proven high potential of crossbred dairy cows indicates there is potential for investment in dairy development in order to increase the quantity and quality of milk marketed and to increase farm household incomes. Presently, the traditional dairy herd management system is not supported by the introduction of improved breeding and feeding systems and the local breeds are not differentiated and improved for particular purposes, resulting in low productivity and offtake (Hurissa and Eshetu 2003). This indicates there is scope for production and productivity increases from the current levels through investment interventions: combined improvements in animal feeding, health and genetics and management practices.

1.2 Objectives of the study

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

1. To provide baseline characterization of cattle herd demographics and productivity parameters, and herd growth dynamics over time in terms of cattle herd growth rates, size and structure, and milk offtake rates for representative traditional cow milk production systems and cattle herd size classes;
2. Analyse the potential for transforming traditional smallholder milk–meat livestock systems to improve family dairy systems for commercially-oriented milk production; and
3. To evaluate *ex-ante* the technical and financial impacts of combined investment interventions in cattle health, feeds, artificial insemination (AI) and oestrus synchronization, and dairy genetic improvement in traditional mixed crop–livestock production systems.

This paper is organized as follows. The next section provides a brief description of the data used in the analysis. Section 3 presents the analytical framework guiding the empirical analysis. The empirical model is presented in section 4, while section 5 presents the results and discussions. Finally, the conclusions 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 cattle herd 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 a survey carried out by Save the Children UK in pastoral areas of Ethiopia. Second, the cattle productivity and demographic data (for example, fertility rates, mortality rates and offtake rates) used to generate parameters for various cattle herd characteristics projections was collected using the Delphi technique which involved the use of structured questionnaire to collect technical data from the national and international livestock experts. The data collected using the Delphi method was validated through meetings of and discussions with panels of experts. Third, the costs of production for different livestock enterprises and the prices for valuation of livestock and livestock products were also obtained from the expert interviews and secondary sources based on market surveys. This study is limited to or focuses on the improvement of cow milk production from the traditional mixed crop and livestock production systems which account for most of the cattle population and livestock-dependent human population. There is a growing trend towards intensive specialized commercial dairy cattle production systems, but the scale is still not significant.

3. Analytical framework

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

4. Empirical approach

4.1 Stage-structured cattle herd projection matrix model

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

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

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

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

Where n_{t+1} denotes the 6x1 state vector of cattle herd sizes by sex and by stage of cattle growth at a time $t+1$; n_t is a 6x1 state vector of cattle herd size by sex and stage of cattle growth at time t; and **A** is a square 6x6 Lefkovitch annual

1 It is outerministic because the parameter of population project matrix remains constant over the entire projection time horizon.

stage-structured population projection matrix used to analyse cattle population dynamics in discrete time (Lefkovitch 1965). The **A** matrix is used to generate a new state variable or vector $\boldsymbol{n}_{t+1}$ 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 cattle which is the product of annual parturition rate and net prolificacy rate, the subscripts *j*, *s* and *a* denote juvenile, sub-adult and adult cattle, respectively irrespective of the sex of the cattle and $G_{i,j}$ is the probability that cattle of a given sex in stage *i* will enter the next stage *j* ($j=i+1$) in the next time period; and $P_{i,i}$ denotes the probability of an individual cattle of a given sex surviving and remaining (or persisting) in the same stage *i*. The structure and formulation of Leslie and Lefkovitch matrices are similar but the difference is in terms of the columns and matrix entries. In the case of Leslie matrix, the columns of matrix **A** represent the age of cattle or an animal, while in the case of Lefkovitch matrix the column represents the different stages of growth. The other difference between the two is that the matrix entries in the case of Leslie matrix is given in terms of fecundities in the first row which indicate the reproductive contribution for different cattle growth stages and survival probabilities (p_i) across the diagonals of the matrix. On the other hand, in the case of Lefkovitch matrix, the fecundities are given in the first row, but the survival probabilities are broken down into two: the probability of an individual surviving and moving from class *i* to the stage *j* ($G_{i,j}$) and the probability of an individual surviving and remaining (or persisting) in the same stage *i* ($P_{i,i}$).

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

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

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

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

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

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

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

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

Once the transition matrix **A** is set-up, the next step in the analysis of cattle herd dynamics is to find out the eigenvalues and eigenvectors of the population projection matrix **A**. This is because several important parameters which characterize the cattle herd dynamics emerge from the eigenvalue and eigenvector analyses of the transition matrix **A**. First, the dominant eigenvalue (λ) of matrix **A** represents the finite (asymptotic) cattle population multiplication rate, while log (λ**)** gives intrinsic annual growth rate which is the continuous growth rate per individual cattle in the population. Thus, in the long-run the cattle 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 herd size (or population) is declining (λ <1), the cattle herd size is staying constant (λ=1**),** or the cattle herd size is increasing (λ >1) in the long-run. For example, λ equal to 1.2 means population will increase by 20% per year and λ equal to 0.93 means the population will decrease by 7% per year over the long-run. Second, the normalized eigenvector (w) associated with the dominant eigenvalue gives the stable stage-structured proportion for cattle herd size. Third, the standardized eigenvectors (v) associated with the dominant eigenvalue of the transpose of matrix **A** provide the reproductive values of different stages of cattle production as compared to the juvenile, this measures the relative contributions of different stages of cattle growth to the long-term growth in cattle herd size.

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

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

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

$$n_{t+1} = \lambda * nt \quad (11)$$

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

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

Where $\mathbf{n}_t$ is a vector of cattle population at time *t*; n_0 is scalar and denotes the initial cattle herd size; λ is the dominant eigenvalue and w is the normalized eigenvector associated with the dominant eigenvalue and denotes stable stage population proportions. Similarly, given the stable sex and stage distribution, and asymptotic cattle growth rate, the total commercial live cattle offtake for cattle with i^{th} sex in j^{th} growth stage at any time *t* denoted as $O_{ij,t}$ 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 cattle offtake at a given time period is given by aggregating the carcass offtake rates across sex and stage classes. This shows the quantity of commercial offtake with constant cattle growth rate and stable stage-structure w. Similarly, the milk and other products are obtained using appropriate offtake rates for each product.

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

$$\boldsymbol{n_t} = n_0 * w \quad (14)$$

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

$$O_{ij,t} = O_{ij} * n(0) * \boldsymbol{w} \quad (15)$$

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

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

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

Where **v** is the left eigenvector associated with **A**, and $\langle \mathbf{w}, \mathbf{v} \rangle$ 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 little intervention could have large impact in cattle population growth. However, the problem with the sensitivity analysis is that the values of sensitivity analysis cannot be compared among different demographic parameters when different scales or units are used. Therefore, instead, the unit-free elasticity is calculated from the elements of the transition matrix (a_{ij}) in **A**, the population growth rate, and the elements of the right and left eigenvectors (w_i and v_i) as follows:

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

where 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 unitless, representing a proportional contribution to λ and are often considered easier to interpret than sensitivities, particularly, when the matrix elements are measured in different units or operate on different scales (e.g. survival rates and fecundity rates) (de Kroon et al. 1986).

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

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

4.2 Economic model

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

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

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

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 return to the farm household's labour, land and capital in cattle production and is a farm gate measure of the gross domestic product (*GDP*) for cattle. In general, the higher the *PVGM* the better. Furthermore, if the availability of data allows, the net profit for cattle production can be obtained as the difference between the *GM* and the fixed costs. The net profit indicates the extent to which the cattle producers are earning normal or excess profit and thus reflects the level of competition and risk existing in the cattle sub-sector. However, due to lack of data on the fixed costs for individual farm households it was not possible to compute the net farm income or net profits for the cattle production systems.

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

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

(19)

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

Ex-ante impact assessment

Financial profitability

The financial feasibility of cattle policy and investment interventions is analysed using a multi-year partial budgeting framework. The partial budgeting implies that only the costs and benefits which differ between the 'with' and the 'without' policy and investment interventions had to be considered. Therefore, the net incremental cash flow (given as 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*), and (3) internal rate of return (*IRR*).

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

$$CF_t = (B_t^w - B_t^{wo}) - (C_t^W - C_t^{wo})$$

(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 for the 'with' and 'without' interventions, respectively. Then, the present value *(PV)* of net incremental cash flows from the policy and investment interventions over a T-year planning time horizon is given as:

$$NPV_0 = -I_0 + \sum_{t=1}^{T} \frac{(B_t^W - B_t^{WO}) - (C_t^W - C_t^{WO})}{(1+\delta)^t} = -I_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+\delta)^t} \quad (21)$$

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

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

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

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

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

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 an investment decision, the value of *IRR* is compared with the cost of capital. For example, the value of *IRR* greater than the current lending rate indicates that the investment is profitable. In other words, the investment must satisfy the condition that *IRR* is greater than δ to justify the initial investment interventions. This indicates that the degree to which the return to a livestock investment intervention is comparable to returns to alternative investment options elsewhere and hence competes for the available funds. 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*.

Future production–consumption balance

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

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

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

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

In this projection, the human population projection is based on CSA population projection for medium variant population growth scenario for Ethiopia. Thus, the annual trend growth rate for real per capita GDP is obtained by taking the difference between the average GDP and population growth rates over the last seven years (2007–13). The income elasticity estimates used in the projections of milk consumption are based on estimates, by International Food Policy Research Institute, derived from household income, consumption and expenditure survey data for 2004/05 (Tafere et al. 2012). The income elasticity estimate for beef and dairy products (including milk) is 0.939 and 0.420, respectively (Tafere et al. 2012).

5. Results and discussions

5.1 Results of baseline assessments

Transformation of the MRD crop-livestock production system

Parameterization of dairy cattle herd growth model

Baseline cattle herd size and structure

For the MRD system, two representative cattle production systems are considered: small and medium size herd MRD. The baseline or initial cattle herd size and structure for the MRD production system used in calibrating the cattle herd projection matrices is given in Table 1. In general, the observed cattle herd sizes are very small in the MRD. The average cattle herd size for small herd MRD is two, while the average cattle herd size for medium MRD is six heads of cattle. The structure of cattle herd is analysed at two levels: globally and by sex. The female cattle in small herd size accounts for 56%, while the male account for about 44% of the cattle herd. In in the case of medium herd, the proportion of female cattle herd is 54% and the female adult cattle are dominant classes of cattle for the MRD production system. Furthermore, the adult classes are the dominant classes of cattle accounting for more than 65% of cattle herd in both systems. This structure indicates the importance of cattle reproduction (replacement of oxen and cows) and for draft power and milk production in the traditional cattle production system.

Table 1. Baseline initial cattle herd size and structure for the MRD traditional cattle production system

Stage class	Small herd size			Medium herd size		
		Structure			Structure	
	Herd size	Global	Intra-sex	Herd size	Global	Intra-sex
Young female (F_j)	0.14	0.07	0.13	0.54	0.09	0.17
Sub-adult female (F_s)	0.20	0.10	0.18	0.54	0.09	0.17
Adult female (F_a)	0.78	0.39	0.70	2.16	0.36	0.67
Young male (M_j)	0.16	0.08	0.18	0.48	0.08	0.17
Sub-adult male (M_s)	0.18	0.09	0.20	0.48	0.08	0.17
Adult male (M_a)	0.54	0.27	0.61	1.86	0.31	0.66
Total	2.00			6.00		

Source: LSA.

Cattle herd demographic and productivity rates

The detailed initial sage-specific demographic rates used in calibrating cattle herd projection matrices for the MRD production system are given in Table 2. The cattle demographic rates varied by sex, stage of growth and production systems. It is interesting to note that the observed mortality rates are higher for younger cattle as compared to older or mature cattle. Due to the lack of data, similar levels of live cattle commercial offtake rates are assumed for all MRD production systems. The initial assumed annual survival rate is also similar across different production systems because of the assumed similar levels of annual mortality rates and annual offtake rates. The observed annual fecundity rate among the reproductive female cows is considered to be very low and estimated at about 51% and 52% for small and medium herds, respectively.

Table 2. Stage specific demographic rates used in calibrating cattle herd projection matrices for the MRD traditional cattle production system

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

Source: LSA.

Stage-structured population projection matrices

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

Table 3. Lefkovitch sex-structured population projection matrices for cattle herd in MRD traditional cattle production system

	Stage at year t					
Stage at year *t+1*	F_j	F_s	F_a	M_j	M_s	M_a
Small herd size						
F_j	0.00	0.00	0.26	0.00	0.00	0.00
F_s	0.89	0.47	0.00	0.00	0.00	0.00
F_a	0.00	0.41	0.88	0.00	0.00	0.00
M_j	0.00	0.00	0.25	0.00	0.00	0.00
M_s	0.00	0.00	0.00	0.83	0.43	0.00
M_a	0.00	0.00	0.00	0.00	0.33	0.90
Medium herd size						
F_j	0.00	0.00	0.26	0.00	0.00	0.00
F_s	0.88	0.47	0.00	0.00	0.00	0.00
F_a	0.00	0.41	0.90	0.00	0.00	0.00
M_j	0.00	0.00	0.26	0.00	0.00	0.00
M_s	0.00	0.00	0.00	0.79	0.43	0.00
M_a	0.00	0.00	0.00	0.00	0.33	0.87

Source: LSA.

Simulation of baseline cattle herd dynamics

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

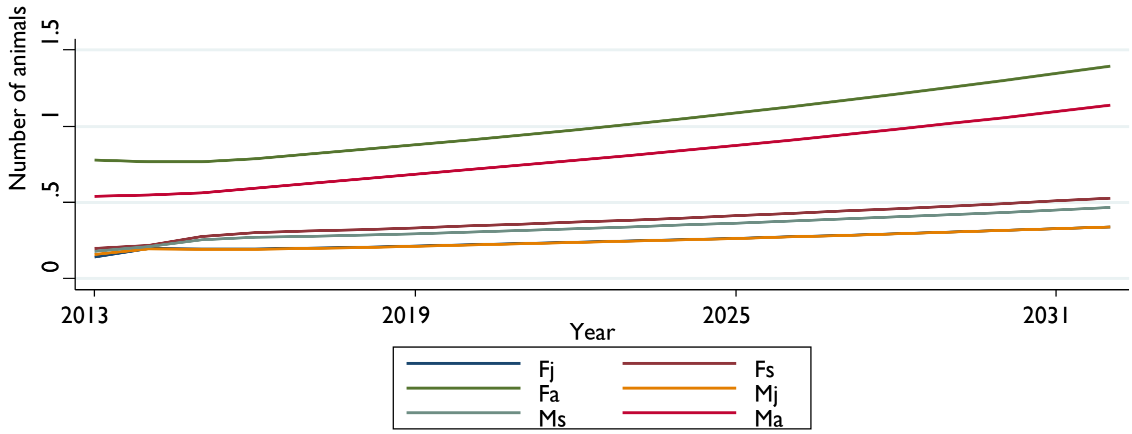
The baseline stable stage distribution, stage-specific reproductive values and annual long-term cattle population multiplication rates for the MRD production system are given in Table 4. The projection of the number of animals for different classes of cattle for small herd and medium herd are given in Figure 1 and Figure 2, respectively. In general, there is upward trend in number of animals for all cattle types. It is observed that under the baseline scenario, the long-run cattle multiplication rate for the MRD production system is 1.04 which implies a 4% annual growth rate in cattle herd.

Table 4. Baseline stable stage distribution (w), stage specific reproductive values (v) and annual long-term population multiplication rate for the MRD traditional cattle production system

Stage class	Small herd size		Medium herd size	
	w	V	w	V
F_j	0.08	1.00	0.09	1.00
F_s	0.12	1.16	0.13	1.20
F_a	0.33	1.61	0.36	1.70
M_j	0.08	0.00	0.09	0.00
M_s	0.11	0.00	0.11	0.00
M_a	0.27	0.00	0.21	0.00
Λ	1.04		1.05	

Source: LSA.

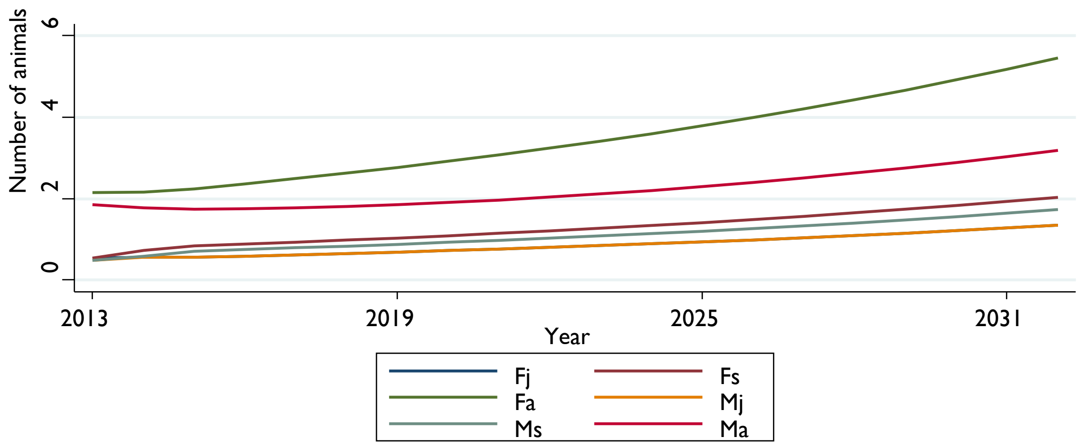
Figure 1: Number of cattle by sex and stage of growth, MRD small herd



Source: Simulation results

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

Figure 2: Number of cattle by sex and stage of growth, MRD medium herd



Source: Simulation results.

Sensitivity and elasticity analysis

The results of sensitivity and elasticity analyses for the MRD production system are given in Table 5. The elasticity analysis shows that the long-term cattle population growth rate is most elastic to the probability that an adult female survives and persists as an adult. The adult female survival contributes about 61% to the cattle herd growth. The annual population growth rate is second most elastic to the probability that sub-adult female survives and stays as a sub-adult. Specifically, a 1% increase in sub-adult survivorship results in about 18% increase in annual multiplication rate. In terms of stages of growth, it is also interesting to note that young female cattle, sub-adult and adult stage contribute 10%, 19%, and 71%, respectively, to cattle herd growth. Furthermore, it is also important to note that the female cattle fertility contributes only 10%, while the annual survival rate contributes about 89% to the cattle herd growth rate. Thus, under the baseline scenario, it is more important to reduce mortality rate than improving the fertility rate of cattle in order to increase cattle growth in MRD production systems.

Table 5. Sensitivity and elasticity matrices from Lefkovitch stage-structured population projection matrix for the MRD traditional cattle production system

	Sensitivity matrix			Elasticity matrix			
	F_j	F_s	F_a	F_j	F_s	F_a	Total
Small herd size							
F_j	0.00	0.00	0.44	0.00	0.00	0.10	0.10
F_s	0.12	0.19	0.00	0.10	0.09	0.00	0.19
F_a	0.00	0.27	0.70	0.00	0.10	0.61	0.71
Total				0.10	0.19	0.71	
Medium herd size							
F_j	0.00	0.00	0.42	0.00	0.00	0.10	0.10
F_s	0.12	0.19	0.00	0.10	0.09	0.00	0.19
F_a	0.00	0.26	0.71	0.00	0.10	0.61	0.71
Total				0.10	0.19	0.71	

Simulation of steady state cattle herd growth dynamics

Stable stage distributions and stage-specific reproductive values

The steady-state stage distribution and stage-specific reproductive values for the MRD production system are given in Table 6. The steady state cattle production is obtained by numerically adjusting the commercial offtake rates by sex and stage of cattle growth. It is to be recalled that the cattle population in the MRD production system is growing under the baseline scenario and, therefore, in order to obtain steady state cattle production there is a need to decrease the cattle herd size by decreasing the cattle classes (sex and stage) which significantly contribute to cattle growth. Thus, the zero cattle growth rate characterizing the steady state is obtained by changing the commercial offtake of female cattle mainly sub-adult and adult female cattle.

Table 6. Steady-state stable stage distribution (w) and stage specific reproductive values (v) for the MRD traditional cattle production system

	Small herd size		Medium herd size	
Stage class	w	v	W	v
F_j	0.08	1.00	0.10	1.00
F_s	0.14	1.12	0.16	1.14
F_a	0.36	1.42	0.39	1.56
M_j	0.08	0.00	0.10	0.00
M_s	0.12	0.00	0.12	0.00
M_a	0.20	0.00	0.14	0.00

Steady state milk production

The annual steady state milk production (litres/herd) by different cattle production system is given in Table 7. The average annual milk production for the small herd size cattle is 108 litres/herd, while for medium herd size cattle the average annual milk production is 335 litres/herd. Thus, the milk production for medium herd size is more than three times of that of small cattle herd.

Table 7. Steady state milk production and cumulative and annualized present value of gross margins by different cattle production systems in Ethiopia[1]

Production system	Average annual milk production (Litres/herd)	Annualized present value of gross margins (ETB/herd)	Annualized present value of gross margins (ETB/head)
MRD			
Small herd size	108.0	14620	7310
Medium herd size	335.0	43370	7228

Note: [1]The time horizon for the projection is 28 years.

Financial profitability

The results of the analysis of financial probability of dairy cattle production at steady state cattle production is given in Table 7. The annualized present value of *GM* for dairy cattle system per head of cattle is also given in Table 7. The annualized present value of outputs per head for cattle for small herd size MRD is estimated to be ETB7310. In the case of medium size herd MRD, the annualized present value of *GM* for cattle outputs per head of cattle is ETB7228. Similar levels of productivity are observed for small and medium herd size cattle herds.

Transformation of the MRS crop-livestock production system

Parameterization of cattle herd growth model

Baseline cattle herd size and structure

The baseline initial cattle herd size and structure for the MRS production system used in calibrating the cattle herd projection matrices is given in Table 8. The observed cattle herd sizes are relatively higher than that of the MRD production system. The average cattle herd size for small herd size MRS is three, while the average cattle herd size for medium MRD is nine heads of cattle. The female cattle in small herd size accounts for 54%, while the male account for about 46% of the cattle herd. The proportion of female in the medium herd is found to be 52%. Similar to other cattle production systems, stage-wise the adult cattle are dominant, while sex-wise the female cattle are dominant in the cattle herd for the MRS production system. However, the level of female cattle dominance is lower for the MRS as compared to other cattle production systems. This might be because of higher draft power requirement for crop production.

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

	Small herd size			Medium herd size		
Stage class		Structure				
	Herd size	Global	Intra-sex	Herd size	Global	Intra-sex
F_j	0.24	0.08	0.15	0.81	0.09	0.17
F_s	0.27	0.09	0.17	0.72	0.08	0.15
F_a	1.11	0.37	0.69	3.15	0.35	0.67
M_j	0.21	0.07	0.16	0.72	0.08	0.17
M_s	0.18	0.06	0.13	0.72	0.08	0.17
M_a	0.96	0.32	0.71	2.79	0.31	0.66
Total	3			9.00		

Cattle herd demographic rates

The detailed initial sage-specific demographic rates used in calibrating dairy cattle herd projection matrices for the MRS production system are given in Table 9. The cattle demographic rates varied by sex, stage of growth and herd size. The level of stage-specific demographic rates assumed in MRS in calibrating the cattle herd projection matrices is similar to the other cattle production systems. In general, it is observed that mortality rates are higher for male cattle as compared to female cattle and for younger cattle as compared to older or mature cattle. The observed annual fecundity rate among the reproductive female cows is considered very low and estimated at about 55% and 59% for small size and medium size herds, respectively.

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

Stage class	Class age range in years	Stage duration in years (d_i)	Annual mortality rate (m_i)	Annual offtake rate (o_i)	Annual survivorship rate (s_i)	Annual fecundity rate (F)
Small herd size						
F_j	0–1	1	0.12	0.00	0.88	0.00
F_s	1–3	2	0.07	0.05	0.88	0.00
F_a	3–11	8	0.04	0.05	0.91	0.55
M_j	0–1	1	0.15	0. 05	0.80	0.00
M_s	1–3	2	0.08	0.15	0.77	0.00
M_a	3–9	6	0.04	0.05	0.91	0.00
Medium herd size						
F_j	0–1	1	0.08	0.00	0.92	0.00
F_s	1–2.5	1.5	0.06	0.05	0.89	0.00
F_a	2.5–10.5	8	0.04	0.05	0.91	0.59
M_j	0–1	1	0.10	0.05	0.85	0.00
M_s	1–2.5	1.5	0.06	0.10	0.84	0.00
M_a	2.5–10.5	8	0.04	0.05	0.91	0.00

Stage-structured population projection matrices

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

Table 10. Lefkovitch stage-structured population projection matrices for cattle herd in MRS traditional cattle production system

	Stage at year t					
Stage at year *t+1*	F_j	F_s	F_a	M_j	M_s	M_a
Small herd size						
F_j	0.00	0.00	0.27	0.00	0.00	0.00
F_s	0.88	0.47	0.00	0.00	0.00	0.00
F_a	0.00	0.41	0.91	0.00	0.00	0.00
M_j	0.00	0.00	0.27	0.00	0.00	0.00
M_s	0.00	0.00	0.00	0.80	0.44	0.00
M_a	0.00	0.00	0.00	0.00	0.33	0.91
Medium herd size						
F_j	0.00	0.00	0.29	0.00	0.00	0.00
F_s	0.92	0.31	0.00	0.00	0.00	0.00
F_a	0.00	0.57	0.91	0.00	0.00	0.00
M_j	0.00	0.00	0.30	0.00	0.00	0.00
M_s	0.00	0.00	0.00	0.85	0.30	0.00
M_a	0.00	0.00	0.00	0.00	0.53	0.91

Simulation of baseline dairy cattle herd growth dynamics

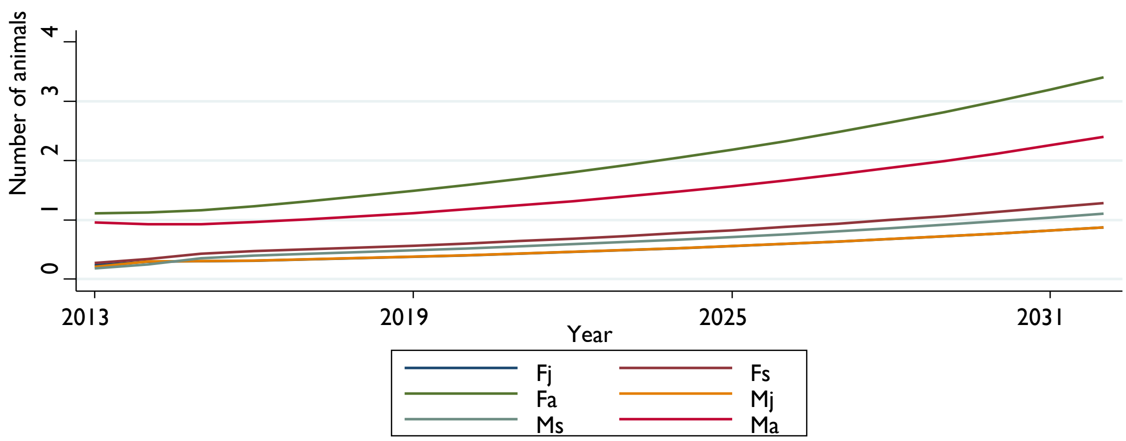
Cattle herd growth rate and stable stage distributions and stage-specific reproductive values

The baseline stable stage distribution, stage-specific reproductive values and annual long-term cattle population multiplication rates for the MRS production system are given in Table 11. The projection of livestock numbers for different classes of cattle in MRS production system are given in Figures 3 and 4. There is upward trend for all cattle types for both small and medium herd size MRS. It is observed that under the baseline scenario, the long-run cattle multiplication rate for small and medium herd size MRS production systems are 1.06 and 1.09, respectively, which imply a 6% and 9% annual cattle growth rate, respectively. The stable stage distribution associated with this constant cattle growth rate for small size herd is 9%, 13%, 34%, 9%, 11%, and 24% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male cattle, respectively. The stable stage distribution is also dominated by female cattle especially adult females. It is also observed that the adult female contributes most to the cattle reproductive value followed by sub-adult female. The reproductive value of male cattle is assumed to be zero in this kind of cattle growth modelling. Similar stable stage distribution and stage-specific reproductive values are observed for both small and medium size herd MRS production systems.

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

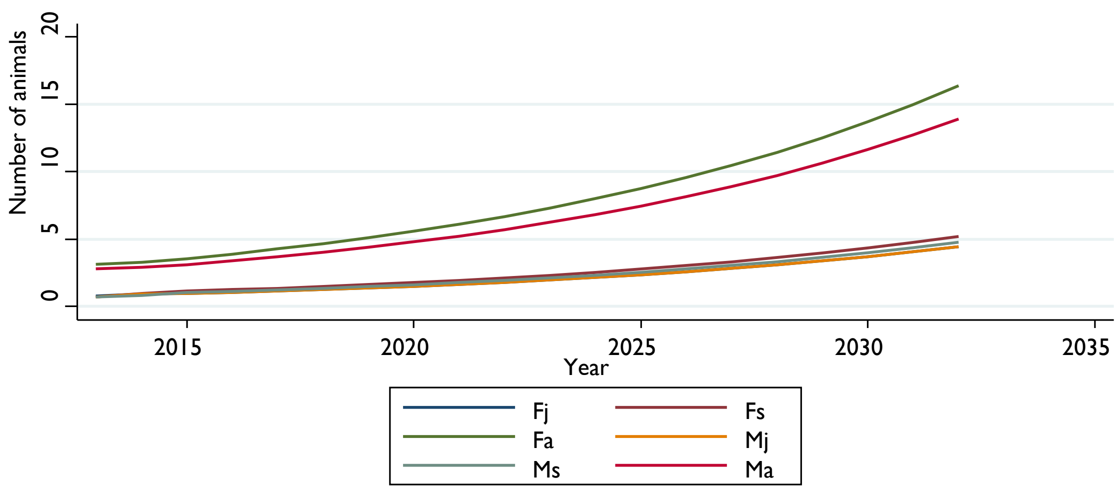
	Small size		Medium size	
Sex-stage class	w	v	w	V
F_j	0.09	1.00	0.09	1.00
F_s	0.13	1.21	0.11	1.19
F_a	0.34	1.75	0.33	1.61
M_j	0.09	0.00	0.09	0.00
M_s	0.11	0.00	0.10	0.00
M_a	0.24	0.00	0.28	0.00
λ	1.06		1.09	

Figure 3: Number of cattle by sex and stage of growth, MRS small herd



Source: Simulation results.

Figure 4: Number of cattle by sex and stage of growth, MRS medium herd



Source: Simulation results.

Sensitivity and elasticity analysis

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

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

	Sensitivity matrix			Elasticity matrix			Total
	F_j	F_s	F_a	F_j	F_s	F_a	
Small herd size							
F_j	0.00	0.00	0.40	0.00	0.00	0.10	0.10
F_s	0.12	0.18	0.00	0.10	0.08	0.00	0.18
F_a	0.00	0.27	0.71	0.00	0.10	0.61	0.71
Total				0.10	0.18	0.71	
Medium herd size							
F_j	0.00	0.00	0.44	0.00	0.00	0.12	0.12
F_s	0.14	0.17	0.00	0.12	0.05	0.00	0.17
F_a	0.00	0.23	0.71	0.00	0.12	0.59	0.71
Total				0.12	0.17	0.71	

Simulation of steady state dairy cattle herd growth dynamics

Stable stage distributions and stage-specific reproductive values

The steady-state stable stage distribution and stage-specific reproductive values for the MRS production system are given in Table 13. The steady state cattle production is obtained by numerically adjusting the commercial offtake rates by sex and stage of cattle growth. This indicates that in order to obtain steady state cattle production, there is a need to decrease the cattle herd size by decreasing certain types of cattle which significantly contribute to cattle growth. Thus, the zero cattle growth rate is obtained by increasing the commercial offtake of female cattle, mainly sub-adult and adult female cattle. As a result, under steady state the percentage offtake of sub-adult female cattle substantially increased.

Table 13. Steady-state stable stage distribution (w) and stage specific reproductive values (v) for the MRS traditional cattle production system

	Small herd size		Medium herd size	
Sex-stage class	w	v	w	V
F_j	0.07	1.00	0.06	1.00
F_s	0.11	1.14	0.08	1.09
F_a	0.28	1.54	0.24	1.35
M_j	0.07	0.00	0.06	0.00
M_s	0.10	0.00	0.08	0.00
M_a	0.37	0.00	0.46	0.00

Steady state milk production

The annual steady state milk production by different cattle production systems is given in Table 14. The annual average milk production for small and medium size cattle herds are 204 litres/herd and 687 litres/herd, respectively.

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

Production system	Average annual milk production (litres/heard)	Annualized present value of gross margins (ETB/herd)	Annualized present value of gross margins (ETB/head)
MRS			
Small herd size	204	27,356	9119
Medium herd size	687	42,243	4694

Note: [1]The time horizon for the projection is 28 years.

Financial profitability

The results of the analysis of financial probability of dairy cattle production at steady state cattle production is given in Table 14. The annualized present value of *GM* for dairy cattle production per herd and head of cattle are given in Table 14. The annualized present value of dairy cattle outputs per herd of cattle for the small and medium herd MRS cattle herd is estimated to be ETB27,356 and ETB42,243, respectively. On the other hand, the annualized present value of *GM* for cattle outputs per head of cattle for small and medium herds is ETB9119 and ETB4694, respectively. The small size cattle herd appears to be more productive.

Beef from dairy system

The intervention in the traditional cattle production system increases the cow milk production and also contributes towards beef production from culled cows, sale of male calves and unwanted female calves. The investment in cattle health, nutrition and genetic improvement also increases weight gain for the cattle classes offtaken from the dairy system. The annual steady state beef production by different traditional cattle production system is given in Table 15. In the case of the MRD, the average annual offtake rate for the small cattle herd is 5%, while for the medium cattle herd, the average annual net offtake rate is 12%. In terms of beef production, for the small cattle herd the average annual beef production per cattle herd is 10 kg, while it is 66 kg/herd for the medium size herd. In the case of the MRS, the average annual offtake rate for both small and medium herd size cattle is 8%. In terms of beef production, for the small herd size cattle, the average annual beef production per cattle herd is 30 kg, while it is 100 kg/herd for the medium size cattle herd.

Table 15. Beef production from dairy system by traditional cattle production systems in Ethiopia[1]

Production system	MRS system		MRD System	
	Average net offtake rate (%)	Average annual beef production from the herd (Kg)[2]	Average net offtake rate (%)	Average annual beef production from the herd (Kg)[2]
Herd size				
Small herd size	5	10	8	30
Medium herd size	12	66	8	100

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

Ex-ante impact assessment of investment interventions

Description of bio-economic simulation analysis

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

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

The investment interventions to transform the smallholder milk production are simulated for traditional smallholder mixed highland systems (MRS and MRD). The traditional smallholder dairy systems (including those in LG) account for 87% of the total production of cow milk, while the SP commercial dairy system contributes 13% (LSA results). The mixed highland and SP systems have major differences in terms of inputs and livestock breeds used. In the commercial SP dairy system, the breeds are improved exotic and/or crossbreeds and the use of veterinary services is widespread. Feed is mostly purchased and largely made up of concentrates and improved forages. In contrast, the traditional smallholder dairy systems rely on low yielding indigenous cattle breeds, with natural pasture as the main source of feed, and there is very limited availability and use of veterinary services.

The Ministry of Agriculture (MoA) and Ethiopian Institute of Agricultural Research (EIAR), and other dairy experts, proposed two different combined interventions to enhance cattle and milk production in the highland traditional mixed (MRS and MRD) and the LG systems. We evaluate crossbreeding, using AI and synchronization, for better genetic potential, combined with improved feeding and veterinary services in the highland mixed smallholder systems where sufficient feed base is expected to be able to support the upgraded exotic blood level. We do not simulate any direct dairy interventions in the LG system, since the experts were unified in maintaining that AI would not work there.

It is assumed that about 70% of households in the MRS and MRD will be reached via the synchronization and AI investment interventions. An animal feed intervention is also required to maximize the potential production benefits from improved breeds (expected from AI and synchronization). In these highland systems, less than 1% of the total feed consumed presently comes from improved forage[2]. Farmers in the highland mixed systems will need to be convinced of the benefits and trained on how to produce better forage on their small farms, including in their backyards or by allocating a small portion of their limited food crop land. Concentrate feed will also need to be supplemented to adult females. The intervention proposes that 1.5 kg of concentrate feed is provided per animal/ day in MRS and MRD small herd systems and 2 kg of feed is provided per animal/ day in the medium herd systems. In this intervention, the farmer incurs an additional ETB53 per animal/year for improved veterinary services across all production systems. Improved animal health will reduce young and adult stock mortality and morbidity.

At the start of the intervention, the adoption rate is expected to be slow, but gradually increase. The adoption rate starts at 10% in year 2 and grows to 80% in year 15, remaining the same until year 20. As a result of a multifaceted approach, including improved breeds through AI and synchronization, improved animal feed and improved animal health through veterinary services, production is anticipated to increase. Under the intervention, the milk yield per cow increases from about 2 litres per cow /day to 6 litres per animal/ day in medium MRS herds and from 1.6 to 4 litres in medium MRD herds. Similarly, the intervention results in an increase of milk yield from 1.8 to 5.9 litres per animal/ day for small MRS herds and from 1.5 to 3.9 litres per animal/ day for small MRD herds. There is also an increase in average weight by different stages of cattle growth which contribute to increased beef production.

2 CSA. 2013. Livestock Agricultural Sample Survey. Report on Livestock and Livestock Characteristics, Volume, II. Addis Ababa. Ethiopia

Given the fact that livestock mortality and morbidity are important causes of economic losses and food security and poverty, appropriate disease control measures are necessary to reduce the negative impacts of livestock diseases and parasites on household and national economy. The high incidence of disease indicates the lack of adequate investment in animal health, nutrition, breed improvement and management practices. However, the funds available for various interventions are also limited which require *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 is discussed in section 4 and is applied to analyse *ex-ante* impacts of combined animal health and feed management interventions in traditional cattle production in different production systems on milk production.

Results of the *ex-ante* impact assessment of investment interventions

The potential productivity, output, income and costs effects of the suggested investment interventions in the traditional dairy cattle production system to improve milk production are analysed *ex ante* at different levels: at the household or herd level, typology of livestock production zones level, and national level. The *ex-ante* financial profitability of cattle investment interventions are based on 20-year projected incremental cash flows comparing 'with' and 'without' intervention scenarios following a multi-year partial budgeting approach as discussed in section 4. The 'without' intervention scenario provides a counterfactual scenario against which to compare the impacts of investment interventions in cattle production. For this purpose, the household level partial budgets, the building blocks for an *ex ante* financial analysis, were constructed for different cattle size classes 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 the *ex-ante* assessment of investment interventions in cattle production in terms of its impacts on future production–consumption balances, financial profitability, and household level income impacts.

Impacts on future milk production-consumption balance

The future impacts of policy and investment interventions in cow milk production is also assessed *ex-ante* in terms of closing the rapidly growing production consumption gap or generating surpluses of milk products for export markets to generate foreign exchange earnings. This projection is also critical to anticipate the magnitude of required future strategies and investments in dairy cattle research and development (policies and technologies), which will be required to close the production–consumption gap in milk production. Considering 15-year projection period (2012–32), the results for milk are presented in Tables 16.

Table 16. Projected national production, consumption, and production and consumption balances of cow milk with and without combined investment interventions in Ethiopia 2028

Status of intervention	National production (10^6 litres)	National consumption (10^6 litres)	Production-consumption balance (10^6 litres)$^+$	Production as a percent of Consumption (%)
Without	6480	8439	-1958$^+$	77%
With	11,453	8439	3015	136%

Note $^+$ negative values indicate deficits while positive values indicate surpluses.

The results of projections of the production and consumption of cow milk 'with' and 'without' investment interventions are presented in Table 17. Without investment intervention, the total cow milk production in 2028 is projected at about 6.5 billion litres. As a whole, without investment intervention the self-sufficiency ratio in cow milk production is about 77% (with a deficit of 2 billion litres). Therefore, investment is needed to close the future cow milk production–consumption gap. The combined policy and investment interventions resulted in a significant improvement in the self-sufficiency ratio for cow milk from 77 to 136%.

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

Impacts on financial profitability

The results of the *ex-ante* financial profitability of the combined investment analyses by dairy cattle production systems in Ethiopia are given in Table 17. In the case of MRS, the *NPVs* are positive in all cases, all the *IRRs* are greater than the assumed discount rate of 10% and the *BCR* is also greater than 1 in all cases. In general, all the financial performance criteria used indicate the financial viability of combined dairy cattle investment interventions in the MRS system.

Table 17. Returns to AI and estrous synchronization in traditional cattle production systems in in Ethiopia (2013–32)

Cattle production system	Herd size group	Indicators of return to investment*		
		NPV (ETB 10^6)	*IRR* (%)	*BCR*
MRS	Small	4657	28	1.50
	Medium	40,840	24	1.52
MRD	Small	-275	9	0.97
	Medium	-4840	4.5	0.84

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

In contrast, it should be noted the AI and synchronization led investment scenario in the MRD is not economically viable, probably since MRD areas have high ambient temperatures, poor rainfall, inadequate grazing resources, and limited availability of crop residues. These negative factors result in a lower productivity impact (less milk and weight gain) for the combined improved genetic (AI and synchronization), animal health, and feed intervention in the MRD system.

Impacts on household income

In order to assess the household level income and poverty impacts of investment interventions in traditional cattle system and in order to improve cow milk production, the 20-years cumulative incremental benefits and costs from combined (animal health, nutrition, AI and synchronization) investment interventions were annualized assuming a discount rate of 10%. The results are presented in Table 18. Five performance measures were derived; annual incremental benefits per herd, annual incremental costs per herd, annual net incremental benefits per herd, annual net incremental benefits per head of cattle, and annual incremental per capita income. The annual incremental costs include both capital investment and recurrent costs. The size of annual incremental costs required indicates whether the investment or costs 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 cattle is obtained by dividing the annual incremental net benefit per heard by cattle herd size. This measures the productivity of cattle in different production systems. The annual net incremental per capita income is obtained by dividing the annual net incremental benefit by average family size (assuming an average farm family size of 4.7 people). The results are presented by cattle production systems and cattle herd size classes.

Table 18. Household level estimates of discounted annual incremental benefits and costs due to combined investments interventions in dairy cattle health, nutrition, AI and estrous synchronization service in mixed crop–livestock cattle production systems in Ethiopia

Cattle production system	Herd size group	Annual incremental benefits (ETB/herd)	Annual incremental costs (ETB/herd)	Annual net incremental benefit (ETB/herd)	Annual net incremental benefit per head of cattle (ETB)	Annual net incremental benefit per capita Income (ETB)
MRS	Small (3)*	2110	1295	815	272	63
	Medium (9)	8967	5901	3066	341	52
MRD	Small (2)	500	514	-14	-7	-3
	Medium (6)	1731	2068	-337	-56	-16

Source: Based on LSA results. Note: the annual incremental benefits and costs are obtained by annualizing the 20-years cumulative cash flows using a discount rate of 10%.

The income impact of combined investment intervention in dairy cattle production varied by dairy cattle production systems and cattle herd size classes. The highest annual incremental per capita income of ETB63 is obtained from the investment in small size cattle farm in the MRS, followed by medium size cattle farm with average annual incremental per capita income of ETB52. In the case of the MRD, negative annual incremental per capita income is observed for small and medium size cattle herd classes.

6. Conclusions and recommendations

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

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

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

The results of bio-economic simulation analysis indicate that the combined investment interventions in cattle health, feeding, reproductive and management practices to reduce young stock and adult stock mortality and to improve dairy breed through AI and synchronization is financially viable and enhances Ethiopia's milk self-sufficiency ratio and has significant impact on cattle keepers income. The implementation of the proposed combined investment intervention requires strong private and public partnership and involves changes in public and private sector veterinary service provisions and public investment. Some of the key policy issues are highlighted below.

To realize the expected milk increases in the MRS, however, sufficient feed availability to meet the increased feed demand arising from the improved breeds will be required in the areas where AI and synchronization are implemented. Specialized extension services will also be essential to support and backstop farmers in the intensive management required for the crossbred milking cows.

In the highland MRS smallholder dairy system, land allocation for forage and fodder production to maximize the genetic potential of crossbreeds will be essential to meet future feed requirements. Although the forage intervention assumes that smallholder farmers will allocate their scarce land for forage production, farmers will need to be made aware of the benefits of fodder production and improved animal feeding.

In addition to fodder, crossbred milking cows will also require concentrate feeds. As dairy cattle population increases, the demand for concentrate feed will also increase. At present there are not enough grain mills and oil processing plants to cater for the present needs of existing dairy cows, much less the anticipated growth in the number of dairy cows. Incentives to promote investments in the agro-processing industries would pay huge dividends in terms of meeting the growing concentrate feed gap.

Perhaps, most importantly, to sustain a regular, sustained increase in the volume of milk produced and marketed, establishing more processing capacity will be essential. Although there is strong evidence that dairy processors are ready to invest in new and increased capacity, they are often discouraged and hindered by bureaucratic obstacles to investing. Besides having fair access to bank credit, investors will need to be supported in their efforts to create the milk collection and supply chains needed to connect farm milk producers to their processing facilities, through cooperatives or directly. As well, before potential smallholder dairy farmers will make the investments required to produce the amount and quality of milk required by processors, they will need to be assured of a regular, daily market for their milk.

The milk supply and quality standards of processors will also need to be met. Government action will be needed to establish and enforce quality based payment incentive schemes, including the training of milk collectors and farmers on how to participate effectively in the schemes. As well, given that there are presently few assured, regular marketcentres for dairy products in Ethiopia, with the exception of a few major urban areas, poorly functioning markets presently negatively affect investment in dairy production and processing, as well as consumption growth in the country. Milk production and consumption cannot be expected to increase substantially unless well-functioning product distribution and marketing systems, bridging rural supply and urban demand, are also in place. Meanwhile, demand for milk in rural areas is for fresh milk and is currently satisfied by home production or the direct sales of raw milk. The demand for processed milk in rural areas is almost non-existent and this is not expected to change in the near future.

The potential for transforming the dairy industry in Ethiopia is indeed great, yet the challenges should not be under-estimated. For success to be achieved, there will need to be government investment in more effective extension services, AI infrastructure and health services, as well as more conducive policies and laws establishing clear sanitary standards and regulations, together with enforcement. Similarly, investment from the private sector will also be needed and these will only be realized if the government creates a supportive investment climate with reduced bureaucratic obstacles to obtaining land to set up and build dairy agribusinesses. Programs to promote market development and trade by fostering business linkages, by providing technical and business training to all value chain actors, and by promoting technology transfer will also be necessary to achieve the anticipated developmental results shown possible in the dairy investment scenario.

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