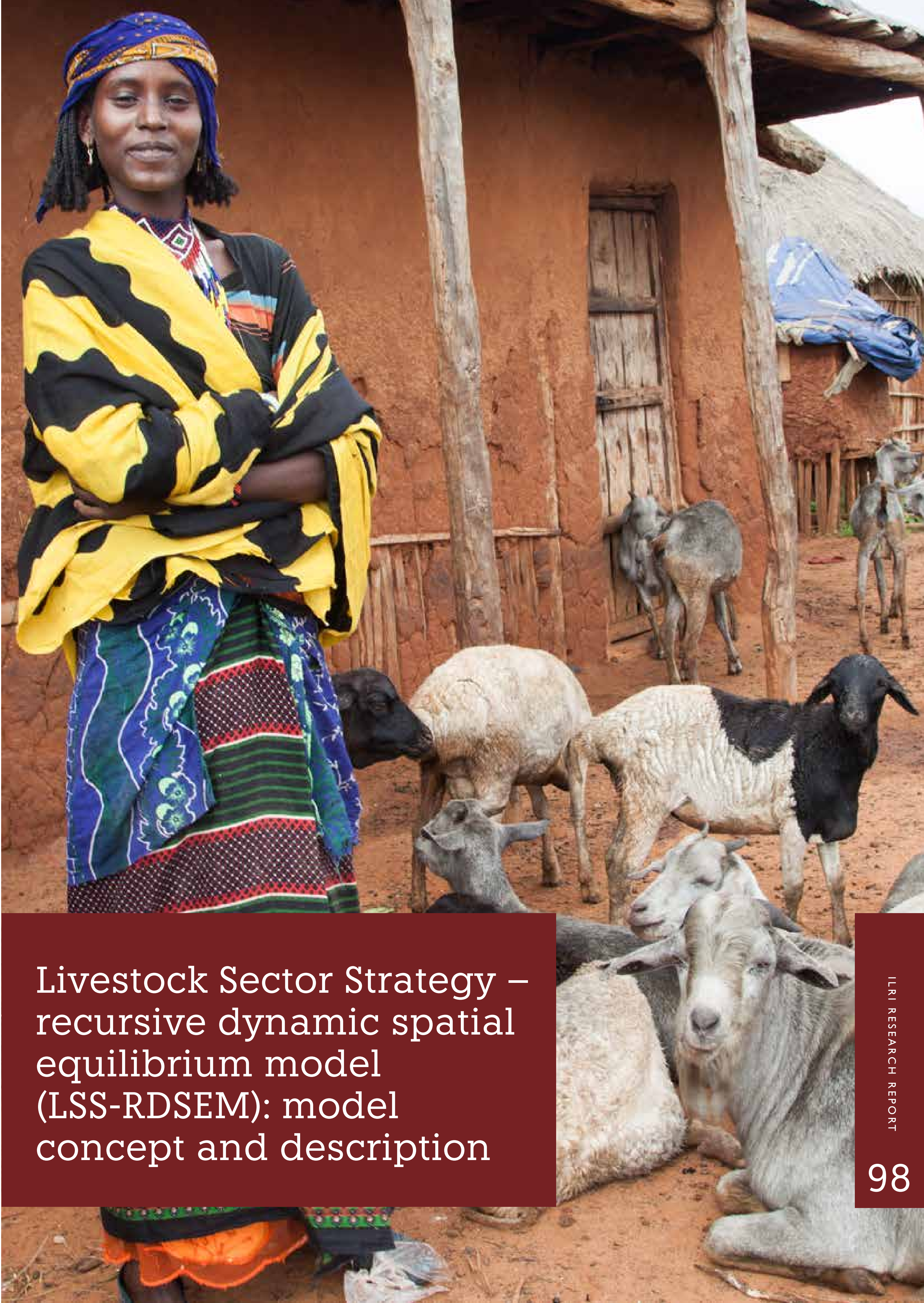

Livestock Sector Strategy – recursive dynamic spatial equilibrium model (LSS-RDSEM): model concept and description

ILRI RESEARCH REPORT

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International Livestock Research Institute

December 2021

ILRI thanks all donors and organizations which globally supports its work through their contributions to the CGIAR Trust Fund

Editing, design and layout—ILRI Editorial and Publishing Services, Addis Ababa, Ethiopia.

Cover photo—Grazing cattle near homestead in northern Ghana (photo credit: ILRI/Dolapo Enahoro)

ISBN:92–9146–701–4

Citation: Bahta, S., Enahoro, D., Wanyoike, F., Mensah, C., Dizyee, K., Rich, K.M. and Karugia, J. 2021. *Livestock Sector Strategy – recursive dynamic spatial equilibrium model (LSS-RDSEM): model concept and description*. ILRI Research Report 98. Nairobi, Kenya: ILRI.

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Acknowledgements

The model development presented in this report was funded by the Bill and Melinda Gates Foundation (BMGF) project, Policy Options for Livestock Investment, Capacity Improvement and Equitable Solutions (POLICIES). The authors also received funding support from the CGIAR Research Program on Livestock (CRP Livestock) and Policies, Institutions and Markets (PIM). We gratefully acknowledge the contributions of CGIAR staff – Isabelle Baltenweck, Nicoline de Haan, Immaculate Omondi and An Notenbaert; and of the following independent consultants – Manitra Rakotoarisoa, Kidus Nigussie, Ricardo González-Quintero and Noah Kofi Larvoe. This report has not undergone the standard peer review of the International Livestock Research Institute (ILRI). The authors bear full responsibility for all content, errors and omissions.

Abstract

Rapid changes facing the livestock sector of low- and middle-income countries, including unprecedented demand for livestock-derived food products, suggest a critical role for quantitative foresight models and analytical approaches. Methodologies that will be most appropriate should be well-suited to quantitative measurement of the economic impacts of investments and policies in the livestock sector, while accounting for issues related to gender dynamics and environmental impacts. This report presents the 'Livestock Sector Strategy – recursive dynamic spatial equilibrium model, or LSS-RDSEM,' developed by the International Livestock Research Institute (ILRI) to support its work with national governments and technical partners involved in the development of livestock sector investment strategies. LSS-RDSEM comprises a core economic market model with linkages to bio-economic and socio-economic components that depict important characteristics of livestock herds or the livestock sector. It can be used to analyse the ex-ante impacts of policies and investments in areas such as animal health, feed technologies and livestock genetics, with impacts measured in production, supply and prices of livestock-derived food products plus welfare indicators derived from these. This report presents the concept and structure of LSS-RDSEM.

Abbreviations and acronyms

AASS	Annual Agricultural Sample Survey
ASF	Animal-Source Food(s)
CIRAD	The French Agricultural Research Centre for International Development
CLEANED-R	Comprehensive livestock environmental assessment for improved nutrition, a secured environment, and sustainable development (version written in R)
CRP	CGIAR Research Program
FAO	Food and Agriculture Organization of the United Nations
GAMS	Generalized Algebraic Modeling System
GDP	Gross Domestic Product
GE	Gross Energy
GHG	Greenhouse Gas
GHGe	Greenhouse Gas emissions
HH	Household
ILRI	International Livestock Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
LMIC	Low- and Middle-Income Countries
LMP	Livestock Master Plan
LSIPT	Livestock Sector Investment and Policy Toolkit
LSMS	Living Standards Measurement Survey
LSS	Livestock Sector Strategy
LSS-RDSEM	Livestock Sector Strategy – recursive dynamic spatial equilibrium model
MITI	Ministry of Industry, Trade and Investment
MM	Multimarket (model)
MT	Metric tonnes
NBS	National Bureau of Statistics
NPS	National Panel Survey
OCGS	Office of the Chief Government Statistician
PE	Partial Equilibrium (model)
PIM	Policies, Institutions and Markets
PO/RALG	President's Office, Regional Administration and Local Government
PSM	Post-Solution Models
QUAIDS	Quadratic Almost Ideal Demand System

S&ASF	Staples and animal-source foods
Tsh	Tanzania shillings
USD	United States Dollar
USDA	United States Department of Agriculture
VPM	Vietnam Pig Sector Model

Introduction

Demand for livestock products has been rising rapidly in many low- and middle-income countries (LMICs), mainly fueled by income increases and burgeoning opportunities for the sector in these regions (Fukase and Martin 2020). Further, the livestock sector in developing countries has played an essential role in promoting economic development, supporting livelihoods and generating employment, including for women and youth (Herrero et al. 2013). At the same time, while livestock represented up to 20% of agricultural Gross Domestic Product (GDP) in the developing world (and 40% in developed countries) in the early 2010s, the sector received less than 0.15% of overseas development assistance to LMICs in that period (Smith 2014). However, as more LMICs revisit the prospects for agriculture-led growth amid mounting economic, socio-political and environmental challenges, attention is turning to the potential contributions of the livestock sector (Enahoro et al. 2018; Enahoro et al. 2019a).

To deliver the untapped potential presented by the livestock sector, both greater investment and returns on that investment must be increased (ILRI 2019). An important component for spurring sustainable development of the livestock sector will be producing an evidence base that can guide proposed government policies and inform on returns on strategic investments made by public and private sectors alike (Pica-Ciamarra et al. 2014). While many types of technological interventions associated with breeding, genetics, feeding, vaccines or animal health exist to support the livestock sector, their returns will be context-specific. These varying contexts need to be well accounted for in the analysis to support decision-making by public or private investors. For example, given the biological lags implicit in many livestock sectors (particularly ruminants), returns on investment may not manifest in the short term, resulting in their omission in standard investment analyses of agricultural systems. As such, dynamic herd behaviours, often ignored in tools of ex-ante impact assessments for the livestock sector are hardly accounted for in many of the analytical tools used. Finally, choice of interventions in the livestock sector may involve trade-offs and/or synergies between economic objectives (such as return on investment, national income as measured by GDP, etc.) and non-economic ones (such as social and gender equity, climate goals, environment and political economy), all of which need to be articulated in a clear, objective manner to aid decision-making.

Through the development of readily deployable *ex-ante* impact assessment models, ongoing work led by the International Livestock Research Institute (ILRI) seeks to contribute the necessary infrastructure to support local, national and regional livestock decision-making in policy spheres (Bahta et al. 2020). ILRI's approach is to apply fit-for-purpose modelling platforms that quantify and prioritize the net benefits of different technologies and interventions, assess their geographic and social appropriateness and outcomes, and inform sustainable business model development for uptake. The current analytical approach considers two main sets of models: multimarket models that generate sector-level (i.e. at the level of a national production system) evidence on how prices, trade and livestock/feed markets adjust to different investment options; and value chain models that assess specific livestock value chains of interest which aim to consider how different technological interventions influence marketing and behaviour of different economic actors. This report documents the multimarket component of the ongoing model development.

The report presents the concepts and structure of the Livestock Sector Strategy – recursive dynamic spatial equilibrium model, a multimarket model developed at ILRI to support its work by guiding and informing the implementation of livestock sector investments, primarily the Livestock Master Plans (LMPs).[1] It starts with the origins and previous applications of the model. The specification of the model is then presented, which includes descriptions of multi-dimensional and interacting components or modules of the modelling framework. Input data required to implement the model are presented, with focus on a pilot test for Tanzania.

The report contributes to the current discussion between ILRI and partners about which modelling approaches will be most suitable for a new generation of LMPs.

1 https://www.ilri.org/livestock-master-plans

Background and model concept

The initial LMPs developed by ILRI and partners have relied on an investment and policy framework dubbed LSIPT: the Livestock Sector Investment and Policy Toolkit (FAO, CIRAD and ILRI 2020). Use of the LSIPT toolkit in LMP development involves the collection of baseline data and parameterization of its herd dynamics and farm and household models. The resulting outputs are then used to develop livestock sector strategies that compute returns under a range of livestock investment scenarios for a projected 15-year period. A major weakness of the use of LSIPT, however, is its inherent assumptions of fixed prices through multiple years and the absence of possibilities for market-based adjustments at the herd level. These constraints limit the capability of the current analytical framework to simulate possible changes in and evolutions of markets and trade that affect livestock systems and investments within this framework. Gender and environmental considerations, amongst others, are also not given sufficient emphasis.

In response to these limitations, new, complementary models are being added to the suite of LMP tools that would add more robust, fit-for-purpose modelling platforms and that can generate a wider range of scenarios and analyses to guide investments and improve uptake (Bahta et al. 2020). The main approach to sector-wide modelling within this suite of expanded tools is the multimarket (MM), partial equilibrium (PE) modelling approach. Multimarket models are valuable tools when the main drivers of system change arise within the modelled system. With this approach, impacts generated by the market model are specific to the system in that the effects of various shocks on sectors are only quantified for segments that are directly modelled. Changes in livestock supply and prices are directly modelled, as are changes in the crop sector for which there is a direct demand for livestock animals. On the other hand, changes specific to other sectors like manufacturing, on which the livestock sector has an impact, could be more indirect and are largely ignored.

LSS-RDSEM, the multimarket model under development for use in the LMPs, originates from a sector model previously developed by Rich and Winter-Nelson (2007). The initial version of the model was applied in the analysis of the dynamic socio-economic effects of foot-and-mouth disease across different regions in South America. A more recent adaptation, called the Vietnam Pig Sector Model (VPM), has been applied in the simultaneous analysis of the pig and maize sectors in Vietnam and Uganda (Lapar et al. 2018). LSS-RDSEM is a spatial multimarket model of the national livestock sector that is disaggregated across different sub-national regions. In its linkage to LMPs, the sector-level model uses baseline LSIPT data as inputs while tailoring Livestock Sector Strategies (LSSs) to run scenarios of alternative investment options. In this way, the new sector-level model replaces the ad-hoc approach to LSS development with a more rigorous platform that can accommodate economic and non-economic dimensions of impact. Further innovation within this modelling framework has been to couple herd dynamics simulation with economic behaviour, allowing the biophysical aspects of herd growth to be influenced by sector investments rather than be deterministically assumed. A more detailed description of LSS-RDSEM follows.

Model specification

A partial equilibrium model of the livestock sector, LSS-RDSEM specifies regional commodity supply and demand relationships within a core multimarket model of country demand, supply, and trade of livestock food and feed crop products. Ongoing developments extend this core economic model to include the simulation of livestock herd dynamics and feed management, and to calculate indicators of food security, environment, plus gender and equity, all linked to livestock sector outcomes (Figure 1).

Figure 1: Visualization of the module interactions in LSS-RDSEM.

The optimal mathematical solution derived from the core multimarket model takes herd-level animal and feed management into direct consideration, while a set of post-solution models (PSMs) are specified. These calculate secondary or derived indicators of welfare based on the model's primary solutions. The details follow.

Core economic model

As the core economic model has been previously documented, for example, Rich and Winter-Nelson (2007) and Lapar et al. (2018), its details are not repeated in this report. We, however, provide a summary of the model's key attributes in Appendix 1. The core model uses mathematical equations derived from first-order, Kuhn-Tucker conditions of a quadratic programming problem to denote the production, consumption and trade of livestock food and feed products for a selected country. The model equations (not presented here) represent crop area, crop yield, total crop supply (as the product of area and yield), livestock supply volume, livestock feed demand, food demand volume, commodity inflows/outflows (to/from regions) and import and export flows across country borders. Solving the model generates equilibrium values of supply, demand, and trade quantities of livestock and other commodities, as well as consumer and producer prices and incomes. Livestock production in the model can be disaggregated by producer typologies (e.g. traditional versus commercial versus modern), while markets can be differentiated by destination (e.g. traditional rural versus urban, modern urban, and import/export). The first-level administrative unit within the country (e.g. states, regions, counties) can be defined as the model's primary unit for market analysis. Livestock production and consumption are simulated at this level to inform inter-regional trade (or movement of products) within the country and with the rest of the world. A current extension of the core model introduces policy simulations around two types of public policy: subsidies and tariffs. The policy effects are traced through livestock and crop (feed) markets, household or government incomes, while technology interventions can be simulated through their effects on the supply and prices of livestock products. Ongoing model updates will further extend policy simulations to their herd-level impacts. For example, tracing the effects of livestock prices on herd stocking and offtake rates, and facilitating direct simulation of the direct effects of herd-level interventions (such as genetics and feed technologies) on regional livestock markets and trade.

Herd dynamics

A model has been developed in GAMS that replicates the herd growth dynamics model known as Dynmod (Lesnoff 2008).[2] This work is documented in Punt et al (2021). Dynmod simulates the dynamics of the size of a livestock population and the number of animals produced per year, calculating animal numbers or herd size, live weight, meat production and secondary production of milk, skins and hides, plus manure. The first version of Dynmod was developed jointly by CIRAD and ILRI, with subsequent model maintenance and updates managed by CIRAD.[3] The version now reported in **Punt et al. (2021)**, which is written in the programming language GAMS, has been developed with the primary objective of providing the flexibility to endogenize herd growth rates of livestock supply in the multimarket model through coupling a sector market model to the herd growth model. In turn, purchase and offtake rates in the herd model will respond to price and other market signals from the herd model. The herd growth model can also be coupled (in an aggregated format) to general equilibrium models and others in a similar spirit, to facilitate studies investigating economy-wide implications of livestock sector changes and interventions. A simplified methodology of how dynamic herd growth behaviour links to a livestock sector economic model is presented in Appendix 2.

Feeds and environment

The specification of livestock feed management and environmental impact assessment in LSS-RDSEM will build on approaches recently developed at ILRI. A novel linking of IMPACT, a global economic model and CLEANED-R, a landscape-level environmental impact assessment tool, has previously been used to analyse environmental impacts related to livestock-induced use change in Tanzania (Enahoro et al. 2019b; Kozicka et al. accepted). Another novel model integration has linked a macro-economic model to a rangeland simulation model to investigate livestock feed scarcity in southern Africa (Enahoro et al. 2021). The feed module development seeks to expand the framework to capture simultaneously, multi-dimensional aspects of livestock-related environmental impacts, including greenhouse gas emissions, the impacts on land, soils, water, biodiversity resources and nutrient mining. See Appendix 3 for the conceptual framework on interactions among feed basket composition, herd characteristics and the derived productive and GHG effects.

2 https://data.ilri.org/portal/dataset/integrated-livestock-systems-and-economic-modeling

3 http://livtools.cirad.fr/dynmod.

Diets and food security

Robinson et al. (2015) fully describe a post-solution calculator of food security used in their partial equilibrium model of the global agricultural and livestock sector. In that simulation, socio-economic variables related to per capita calorie availability, access to education, the quality of maternal and childcare, and health and sanitation were used statistically to explain malnutrition (measured as the number of children aged under five who are underweight) and hunger (total population at risk of hunger).

Our model adaptation which follows the general approach in Robinson et al. (2015), focuses on household-level characteristics, and only on components of total food supply related to livestock-derived foods (Appendix 4). In a specific adaptation to the livestock sector, projections of ASF availability will be linked to the supply of nutrients such as vitamin A and iron, and nutrient intake levels and hidden hunger (Alonso, Dominguez-Salas, and Grace, 2019). The model adaptation is flexible enough to, in addition, account for the influence of national characteristics such as religion and culture, on the supply of livestock-derived food.

Employment

Gainful employment in rural areas remains one of the key development challenges in many developing countries and a potential endpoint for livestock-mediated interventions. As such, measuring the impacts that LMP-related changes in the livestock sector will have on employment is an important component of the model extensions. Our approach seeks to adapt Frija et al. (2020), which developed a methodology for assessing the employment-generation impacts of direct investments made to enhance livestock productivity. Adapting the use of published employment elasticities, the proposed method translates overall GDP growth resulting from livestock sector investments into geographically- and gender-differentiated measures of new employment. The method in Frija et al. (2020) can further calculate gender-disaggregated impacts of livestock sector policies, basing this on historical observations and documented relationships between livestock sector dynamics and socio-economic welfare. This application has been previously tested using national-level data for Tanzania (Enahoro et al. 2019c).

Gender

Expert consultations and targeted literature review inform the current approach to gender modelling in LSS-RDSEM. While expert consultations have identified these elements as the primary ones to consider, a review of the literature showed that limited documentation exists where sector- or economy-wide models relevant for livestock sector planning have captured the diverse roles of women in agriculture/livestock at any level of detail. These roles will include their time inputs, participation and performance in livestock production activities, technology adoption and risk management. The specific impacts of changes in livestock sector dynamics on women and men are similarly under-represented in the economic models widely used to support livestock development and planning at sector scale (Mensah et al. in prep).

Our modelling of gender dynamics has thus adapted a two-phased approach.[4] In the short term, we use historical data to establish country-specific relationships between livestock sector fundamentals (such as livestock ownership) and gender-differentiated outcomes (such as incomes and diets), projecting the different impacts of livestock investments on men and women based on changes in these factors over time. In the long term, a more challenging adaptation of gender dynamics will be implemented, wherein the model's specification of livestock production and value chains will be updated to reflect

4 https://www.ilri.org/news/more-money-setting-livestock-investments-gender-equity-outcomes

the different roles of men and women. We present a modelling approach for linking the core multimarket model to post-solution calculations of secondary impacts. Specifically, it integrates the livestock sector model with a statistical model of the relationship between gender and livestock using parameters derived from a regression analysis of data from nationally representative household surveys. A variety of statistical approaches have been explored, including Mbukwa (2013), Siliphouthone and Yasunobu (2016), Phami et al. (2020) and Felker-Kantor and Wood (2021). The approach of Rae and Zhang (2009) is described in Appendix 5.

Model input data for Tanzania pilot

For a pilot test of the model, baseline parameters were obtained for Tanzania from national databases, published literature, and previously obtained data from expert opinion (e.g. collated during Tanzania LMP development) (Appendix 6). In addition, parameters such as elasticities (i.e. the response of demand or supply to a 1% change in income or prices) have been estimated using household survey data and aggregated data from Tanzania. A Quadratic Almost Ideal Demand System (QUAIDS) analysis was conducted to generate estimates of food demand elasticities from household-level data. Use of the QUAIDS model is described in Appendix 7.

Secondary data

Key data for parameterization of LSS-RDSEM to the context of Tanzania have been derived from secondary sources, including national databases. A listing of the model parameters and their data sources is presented in Appendix 6. Data on area, yield and production of maize, the major feed crop used for livestock, as well as livestock production numbers, were obtained from the 2014/15 Annual Agricultural Sample Survey (AASS) report and data set (NBS 2016). The AASS for 2014/15 Agricultural year is conducted by the National Bureau of Statistics (NBS) in collaboration with the Ministry of Agriculture, Livestock and Fisheries, Ministry of Industry, Trade and Investment, the President's Office, Regional Administration and Local Government (PO/RALG) and the Office of the Chief Government Statistician (OCGS). Data on feed demand/requirements, feed prices, and weight of the animals were derived from Tanzania's LMP-LSIPT database (Michael et al. 2018). The classification of livestock under different production systems was informed by the LMP-LSIPT database data prepared by ILRI for 2016, where the number of livestock kept under each production system was estimated (ibid). Data on urban and rural consumption of maize and livestock for each of the 30 regions of Tanzania was drawn from the 2012 Population and Housing Census and the 2014/15 AASS (NBS 2013).

Parameters requiring urban and rural distributions were based on estimates from the 2012 Population and Housing Census, while regional projections of urban-rural populations were obtained from the NBS National Population Projections 2018 report (NBS 2018b). Urban and rural distributions of per capita income for the regions in 2015 were obtained from the National Accounts Statistics of Tanzania Mainland 2012–2018 report (NBS 2019a), as were growth rates used to project regional income for 2015 and 2025. Data on the prices of both livestock and maize for 2015 were obtained from the 2014/15 AASS (NBS 2016). Baseline prices of maize and livestock were obtained from multiple sources such as regional reports quoting prices of maize and livestock in the various regions, Wave Four (4) of the Living Standards Measurement Survey (LSMS) conducted between 2014 and 2015 (NBS 2017) and the 2016/17 Annual Agricultural Sample Survey (AASS) report (NBS 2018a).

Data on world prices of maize and beef imports and exports for 2015 were obtained from the Food and Agriculture Organization of the United Nations Corporate Statistical Database (FAO 2016). Information regarding future prices of maize and livestock was obtained from the World Bank Commodity Markets Outlook (World Bank 2020). The price forecasts for the period 2015 to 2025 were used to estimate the annual growth rates of maize and livestock. Processing cost for maize was obtained from an FAO report on the maize value chain in Tanzania (Wilson and Lewis 2015). Processing cost for livestock was derived using estimates from a previous study (Musa 2019). The year 2015 export and import volumes of maize and beef were obtained from the Tanzania National Food Balance Sheets 2014–2017 report (NBS 2019b), and the United States Department of Agriculture (USDA) trade data for 2015 (USDA 2017). Tax rates for imports of maize and beef were obtained from the Tanzania Business Portal, a trade facilitation platform run by the Tanzania Ministry of Industry Trade and Investment (MITI).[5] Distances between the regions by road and sea were obtained using a direct search on Google Maps as well as a distance calculator from Globefeed.[6] Commodity transport costs were drawn from Mkenda and Campenhout (2011).

Demand analysis to derive model elasticities

To derive the elasticities of demand and income for various ASF statistically, we used data from the 2014/2015 Tanzania National Panel Survey (NBS 2017), where a total of 5,010 households (3,219 rural and 1,791 urban) were included in the survey of households nationally. The survey we used was the fourth round in a series of nationally representative household panel surveys. It covered up to 26 regions in Tanzania and collected information on a wide range of topics, including agricultural production, non-farm income-generating activities, consumption expenditures and other socio-economic characteristics of households.

Methodology

The Quadratic Almost Ideal Demand System (QUAIDS) model was used to estimate the expenditure and price utilities. As in Mekonnen et al. (2012), we adopted the utility tree concept where we assumed that consumers make their decisions in two stages. In the first instance, they allocate their budget to broad categories of expenditure such as food, clothing and education. Given the amount allocated to food, households next decide on the amounts to spend on various food types, including staples and animal-source foods (S&ASF), vegetables, fruits and condiments. It is further assumed that the different categories of commodities are separable so that non-S&ASF expenditure affects the demand for specific S&ASF commodities through its impact on the amount to be allocated to the S&ASF branch. Following Banks et al. (1997) and as in Mekonnen et al. (2012), use of the QUAIDS model allows for curvature in the Engle curve.

Estimation of the income and price elasticities were done using the QUAIDS command by Poi (2012) of the STATA computer package. Details of the QUAIDS model used are presented in Appendix 7.

Results

Table 1 shows the expenditure elasticities for various animal-source food commodities. As expected, the elasticities were positive, implying that changes in demand move in the same direction with changes in expenditure, a proxy for income. That is, if food expenditure increases, demand increases and vice versa. Chicken and milk powder have the highest expenditure elasticities (1.67 and 1.57, respectively, for the entire sample), and the trend is the same in both urban and rural households.

5 https://business.go.tz/

6 https://distancecalculator.globefeed.com

Table 1: Expenditure elasticities for various animal-source food commodities in Tanzania

	All data	Urban	Rural
Sheep and goat meat	1.16	1.31	1.12
Beef	1.26	1.2	1.3
Pork	0.84	0.68	0.87
Chicken	1.67	1.62	1.79
Eggs	0.98	1.01	0.95
Fresh fish	0.59	0.63	0.6
Dried fish	0.41	0.19	0.48
Fresh milk	1.11	1.15	1.08
Milk powder	1.57	1.41	2.63
Other dairy products	0.83	0.78	0.86

Table 2 presents the uncompensated price elasticities of demand for various livestock-sourced food commodities. The results indicate that demand for most commodities is rather elastic, authenticated by the relatively large negative own price elasticities. Commodities with rather large negative own price elasticities include processed dairy products (-19.5), pork (-13.48), goat meat (-7.28), chicken (-5.23), and eggs (-4.75). For most commodities, cross-price elasticities were rather small (<1) and often positive, depicting some substitution cross effect.

Table 2: Price elasticities for various animal-source food commodities in Tanzania

	Goat meat	Beef	Pork	Chicken	Eggs	Fresh fish	Dried fish	Fresh milk	Milk powder	Other processed dairy products
Goat meat	-7.28	-0.14	0.84	0.51	0.13	0.48	0.28	0.28	0.02	0.49
Beef	-0.04	-2.49	0.14	0.04	0.05	0.16	-0.05	0.11	0.00	0.03
Pork	1.67	1.19	-13.48	0.10	-0.15	0.34	0.62	0.50	0.57	1.35
Chicken	0.73	0.18	0.06	-5.23	-0.09	0.43	-0.22	0.55	-0.16	0.34
Eggs	0.40	0.65	-0.22	-0.17	-4.75	0.29	-0.15	0.13	-0.78	1.51
Fresh fish	0.09	0.18	0.03	0.07	0.02	-1.37	0.16	0.03	0.01	0.01
Dried fish	0.12	0.02	0.12	-0.03	-0.01	0.39	-1.57	0.09	0.01	0.03
Fresh milk	0.28	0.46	0.25	0.38	0.04	0.07	0.19	-3.82	-0.03	0.25
Milk powder	0.24	-0.06	-3.49	-1.28	-3.20	0.66	0.39	-0.37	0.21	0.13
Other processed dairy products	1.91	0.51	2.67	0.92	2.02	0.14	0.32	0.99	0.04	-19.05

Model application to Tanzania

The different modules of LSS-RDSEM are under simultaneous development. Some of the developed models/modules are being pilot tested, with varying degrees of progress, based on, for example, alignment to existing or ongoing LMPs and data availability. The main pilot test for the multimarket model framework is for Tanzania, a large cattle producer in East Africa. In a first step, the core economic component of the sectoral model has been adapted to the livestock sector of Tanzania (including cattle, sheep, goats, pigs and chickens), using previous LMP/LSIPT data to test the robustness of the model. Three market types are now modelled in a way that corresponds to the major large ruminant livestock production systems in existence in Tanzania, i.e. traditional (small-scale), commercial or medium-scale, and large-scale. All three production systems have been modelled for beef cattle, while small- and medium-sized systems are included only in the modelling of small ruminants (goats and/or sheep).

LSS-RDSEM does not account for the variation in agro-ecological zones for ruminants. Our analysis instead relies on the model's sub-national disaggregation to capture variations in agro-ecology. As a test case, the model includes seven (7) out of the 30 administrative regions in Tanzania: Mwanza, Shinyanga, Mbeya, Tabora, Mara, Manyara and Geita. These regions were selected for their relatively high livestock production/demand of livestock-derived products, compared to other regions in the country. Regional demand for food and feed products is split into rural and urban in the model. This model has a 10-year horizon (2016 to 2025). The livestock commodities included in this test model are all the priority livestock value chains considered during development of the Tanzania LMP in 2016. These include cattle, goats, sheep, pigs and poultry. The farming systems within each value chain are classified by average herd sizes, as shown in Table 3. The analysis using LSS-RDSEM leads to some early implications about the relative and absolute quantities of demand and supply, plus their changes over time. It also reveals important dynamics between regions.

Table 3: Priority value chains and farm types considered in the test model

Species/value chain	Farm types	Average Herd size
Cattle	Small cattle farms	10
	Medium cattle farms	88
	Large cattle farms	1082
Goats	Small farms	8
	Large farms	72
Sheep	Small farms	8
Pig	Small farms	2
	Medium	3
	Commercial	8
Poultry	Backyard system	1.7 – 58.5
	Layers	1 cycle 12,000
	Broilers	1 cycle 3040

Data source: Tanzania LMP data

Beef production from the seven regions included in the analysis totalled 728,000 MTs in 2016 (Table 3). This represents more than double the amount recorded for cattle meat production in Tanzania (320,000 MT), according to the FAO national statistics (FAO 2020). While additional data and model quality checks still need to be completed, the results could already highlight discrepancies that can exist between published statistics such as those used by the FAO and data obtained sub-nationally (Pica-Ciamarra et al. 2014). The likely discrepancy does not constitute a problem to the model development or subsequent model use. However, it will need to be properly accounted for when interpreting model results and when linking the model to others, such as global change models that make extensive use of published national statistics. Of the model's accounting for total production in 2016, traditional or small-scale beef production represented more than 70%, medium-scale production accounted for more than 29%, while large-scale commercial beef production and products accounted for less than 1%.

The model attempts to track expected changes in livestock demand and supply over time. Initial results of the forward-looking analysis, which are subject to revision following an ongoing model and data validation exercise, are summarized in Appendix 8.

Discussion and next steps

The need has been established for fit-for-purpose, integrated tools for policy and ex-ante impact analysis tools to support decision-making regarding the future of the livestock sector in low- and middle-income countries. This report documents the work that is currently underway to develop a multimarket modelling platform to guide and inform implementation of livestock sector investments that are supported by ILRI, primarily in the context of Livestock Master Plans (LMPs). This is part of a two-component platform offering tools to conduct sector-wide as well as specialized value chain-focused policy and ex-ante impact analysis.

Various degrees of progress have been recorded in conceptualization of the multimarket model framework with its integrated assessment components covering herd dynamics, gender, feeds and environment, employment, plus nutrition and food security. These modules of LSS-RDSEM have mostly been specified in stand-alone mode, with different approaches offered for their linkages and application to integrated analysis. This approach maintains the initial project objective of producing a harmonized set of ready-to-deploy tools rather than the adoption of a mechanical, one-size-fits-all tool with limited practical use. The current approach also comfortably accommodates differences in data and skillsets available to update the model across multiple disciplinary areas. Specifically, development of the feed and environmental module, data analysis informing the modelling of gender dynamics, and validation/simulation tests of a herd dynamics model have been completed simultaneously by deploying complementary teams on data analysis and quantitative modelling.

Pilot testing of the model for Tanzania reveals the potential of the analytical tool for short- to medium-term livestock investment analysis that well accommodates sub-national differences in livestock production and demand. The data needed to implement the model have so far been obtained for Tanzania. When applied to a different country, however, the data documentation for Tanzania should prove a helpful resource to aid researchers on identification of the types of data sources to explore.

Other demands for livestock sector modelling continue to present opportunities for improving the development of LSS-RDSEM (in part or whole). The core economic model is currently being applied to livestock sector modelling in support of LMP work in Kenya, and in a regional economic analysis of feed markets in southern Africa (South Africa, Malawi, Zambia and Mozambique) unrelated to the LMPs. Other LMP development (e.g. India dairy road map development), where the request is for a sub-sector (and not whole sector) strategy, present an opportunity to use the LSS-RDSEM in a scaled-back mode, requiring a less data-intensive framework than that offered by LSIPT. Such an application should provide lessons for future model development and use in data-constrained environments.

Other model development will advance linkages of the multimarket framework to the bio-economic (e.g. herd dynamic) models, fine-tune the development of appropriate, standardized post-solution models for impact analysis and develop mechanisms for testing investment scenarios. The model extension for gender analysis will next focus on explicit simulating of women's roles within the livestock sector and incorporating gender-disaggregated specifications and data in the model's representation of livestock production and demand. This should help better quantify evidence of the benefits of participation of men and women in local livestock value chains.

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Appendices

Appendix 1: Model attributes of Livestock Sector Strategy – Recursive Dynamic Spatial Equilibrium Model (LSS-RDSEM)

Principal Investigators: Sirak Bahta and Dolapo Enahoro

Date: 25 October 2021

Attribute	Attribute description	Details
Overall Model Characteristics		
Objective/Primary Outputs	The types of results, outputs directly generated	Supply, demand, and trade (imports and exports) of livestock food products and livestock feed commodities; farmgate and retail prices
Secondary outputs	The types of results, outputs further calculated from the primary outputs	Producer incomes, consumer expenditures, poverty and food security, (model extensions are to include environmental and gender equity impacts)
Inputs	The types of data needed and sources	See appendix 4 for information on base year data and parameters
Scenarios	Describe the type of scenarios analysis model can be applied to	Socioeconomics (population, income growth), policy (taxes, quotas), technology (supply growth)
Scale	Landscape, national, regional/global, and where currently applied (which countries)	Country model with seven (7) first level administrative units (currently possible to reduce or expand number of regions)
Supply and demand	If production or demand (equations) included in structure	Includes both production and demand sides in the equations
Physical and economic	Biophysical results only, or economic and/or prices also	Economic (currently being expanded to include biophysical, e.g. herd and feed/environmental modelling)
Human welfare	Includes poverty, income distribution, gender, consumer/producer surplus	Under development
Time horizon	Length of period for projections, and unit of time	12-year annual time step from 2016 to 2027 (can be adjusted, e.g. 2014 to 2025)
Livestock systems		

Livestock system categories	Global livestock production system	Livestock production categorized into traditional/small, medium, and large-scale cattle/beef, dairy, sheep and goat, pigs and chickens
System change	Includes modeling of livestock system change e.g. pastoral systems becoming more agro-pastoral	None
Market-sourced feeds	Includes estimates of internationally traded (market) feed types	Maize (current expansion to include other grains, oilseeds and other crops)
Non-market sourced feeds	Includes estimates of non-market source of feed	None
Livestock species	Which livestock species represented	Cattle (dairy and beef), small ruminants, pigs, chickens
Breeds	Level of breed differentiation	None (but systems implicitly include breed differentiation e.g. modern dairy likely includes crossbreds, observed in higher productivity)
Model technical		
Simulation/optimization	Model solution	Complementarity problem (system of nonlinear equations)
Spatial resolution	Pixel, admin/political unit, etc.	Sub-national regions (first-level administrative units)
Software	---	Generalized Algebraic Modeling System (GAMS) https://www.gams.com/
Version	Software release version and date	October 2021

Appendix 2: Description, assumptions, and specification in GAMS of a Livestock Supply Model

General setting

The model assumes a (local, national, or regional) competitive livestock sector that produces and sells live animals and a livestock product (e.g. meat). The sector uses labor (L) and capital (K) as main inputs and is a price taker in both the input and output markets. Depending on the changes in market prices, the herd manager has the choice of producing and selling live animals, meat or both live animals and meat to maximize the sector's profit. Solving the profit maximization problem (given some sector budget or resource constraints) in producing and selling the two outputs leads to the supply equations of the forms:

(A2.1) $X = A.P_l^{\alpha}.P_{llag}^{\beta}.P_m^{\gamma}.R^{\delta}.W^{\sigma}$

where.

X: output level (number of live animals or amount of meat);

A: productivity (a shifter for technical progress);

P_l: price of live animal in ($ per head);

P_{llag}: past (or lag of the) price of live animal (in $ per head);

P_m: price of processed livestock (meat price in $ per tons);

R: rental price of capital (in per cent per unit of capital);

W: wage (in $ per hour) ;

The exponents are elasticity parameters.

In other words, (1) says that the supply of live animal is a function of its own price, the lag (say one-time lag) of the live animal price, the price of processed livestock product, and input prices. The same can be said for the supply of meat. The supply shifter A, an indicator for technical progress, is added.

Totally differentiating the log linear form of (A2.1) leads to:

(A2.2) $x_{l,m} = a + \alpha.p_l + \beta.p_{llag} + \gamma.p_m + \delta.r + \sigma.\omega$

The lower-case variables in (2) are the percentage changes of the corresponding uppercase variables in (1).

The generic expressions in equations in (1) and (2) encompass both the expressions of the supplies of live animals and that of the processed livestock product. As the sector can produce and sell live animals or meat, the cross-price elasticities reflect, for instance, how the change in the price of live animals (one of the inputs in meat production) affects the price of meat, or how the change in the price of processed meat affects the price of live animals.

After a technology and/or some price shocks, the total change in herd stock can be written as

(A2.3) $x_{total} = x_l + x_m$

where is the percentage change due to the (technology and/or price) shocks in the number of live animals directly destined for sale and is the change, due to price shocks, in the number of live animal destined for meat sale.[7]

Xnew = Xold (1+x_total),

As the variables in (3) are in percentage terms, reverting back to variable level to get X_{new} , the updated level (number) of live animals after the price shocks, one has just to compute:

(A2.4) $X_{new} = X_{old}\ (1+x_{total}\ ),$

where X_{old} is the initial level of the number of live animals before the price shocks and is the total change in herd stock.

Finally, with the information on initial price and quantity levels before the shocks at hand, the percentage change in revenue can succinctly be expressed as:

(A2.5) $z = \frac{\sum_j (P_{0j}.X_{0j}).(x_j+p_j)}{\sum_j (P_{0j}.X_{0j})},$

where *j* = live animals, meat. The subscript ***0*** means old (or initial levels of) prices and quantities.

The mathematical derivation of the supply function

where P_l is the price of live animal, P_m price of meat, *C*(.) is the sector's variable cost and *FC* is its fixed costs. The parameter *a* is the level of technological progress (or cost efficiency). Assuming that the amount of meat is a fixed proportion of the unit of live animal, i.e. $X_m = c.\ X_l$, where *c* is the yield in transforming live animal into meat., the first order condition of profit maximization is:

(A2.6) $P_l + c.\,P_m = \frac{1}{a} C'(c, X_l)$

where *C'(.)* is the marginal cost, an invertible function.

Therefore, the livestock supply function is

(A2.7) $X_l = f(a' c, P_l P'_m)$

In other words, the supply is a function of both prices (of live animals and meat) with some productivity and cost efficiency parameters a and c. In an econometric estimation of the elasticity parameters in (7), one may add input prices and past prices of live animals on the right hand side.

To arrive at the expression of the supply function in Equation (A2.1), we assume a profit maximizing sector that produces two outputs Xl (live animal) and Xm (meat). The sector cannot affect the unit prices of live animal P_l and unit price of meat P_m. The joint profit function can be written as

(A2.8) $\pi = P_l X_l + P_m X_m - \frac{1}{a} C(X_l, X_m) - FC$

(A2.7) as control variables and write the supply function described in Equation (A2.1). By analogy, the supply of meat can be derived and expressed with the same generic expression in (A2.7).

7 Assuming that the amount of meat per head of animal is constant, then represents both the percentage changes in the number of live animals slaughtered for meat and the percentage change in the amount of meat.

A final note on the supply function derivation is that we might as well proceed to maximize the joint profit with some resource constraints such as a fixed livestock population (Xtotal =Xl + Xm) and limited supply of inputs (labour, capital) or with other forms of constraints. The constrained profit maximization solutions, nevertheless, converge to the generic expression in (A2.7).

GAMS code for the Livestock Supply Model

```
$Title A basic simulation model on livestock supply response to price
changes (LSRPC), International Livestock Research Institute, July-August
2021.

$ontext
This is a GAMS program simulating the impacts of input and output price
changes on livestock production.
$offtext

Sets
       i input /capital, labor/
       j output /live, meat/
       k supply arguments /liveprice, lvplag, meatprice, capitalprice,
laborprice/;

Parameters
       pdty(i) productivity of input
       /capital 0.5
       labor    0.5 / ;

            Xold(j) initial levels of output
       /live    1000
       Meat     100/;

       Pold(j) initial levels of price in US dollars per unit

       /live    200
       Meat     500/;

*the p(j) price shock is announced here but will also be presented in
table c

       p(j) exogenous price shocks in percent
       /live 10
       Meat 20/

Table n (j,k) elasticity in the supply equations

       liveprice lvplag       meatprice capitalprice laborprice
live   0.5        0.4                 0.1          -0.1     -0.2
meat   0.4        0.3                 0.5          -0.1     -0.2
 ;

Table c(j,k) percentage change in supply argument

       liveprice lvplag       meatprice capitalprice    laborprice
live   10          15            20                10       5
```

```
meat    10         15            20             10     5
;



Scalar f gives amount of meat per head of live animal   /0.3/;
*Scalar Xold is the initial number of live animals in thousands /1000/;

Variables

       x(j) percent change in output

       xh percentage change in the final stock of live animals

       Xnew(j) number of live animals or meat after shocks

       z percent change in total revenue;

Positive variables Xnew;


Equations
       Output change
       Herd inventory change
       Herd size after shocks
       Total revenue change;



       output .. x(j) =e= sum (i, pdty (i)) + sum(k, n(j.k)*c(j.k))

       herd inventory ..    xh =g=    x("live") + x("meat")

       herd size.. Xnew =e= Xold*(1+(xh/100))

          total revenue change.. z=e= (sum(j, (Pold(j)*Xold(j))*(x(j)
+p(j)))/(sum(j, Pold(j)*Xold(j));

Model simulation /all/;

*Solve simulation using lp maximizing z;

Display x(j), xh, Xnew z;


$ontext

Reference: "Comparative Advantage and Multi-Output Livestock Systems:
A Quantitative Approach", Unpublished Paper by Manitra A. Rakotoarisoa
and James N. Trapp, December 1997, Department of Agricultural Economics,
Oklahoma State University, USA.

This LSRPC model is translated into GAMS program in August 2021 and is
only one of the five basic models simulated in the 1997 original paper.
```

```
This version includes an upward sloping supply function for sector-lev-
el resources in the partial equilibrium subproblem. The livestock sup-
ply function is derived from a joint profit maximization of a multi-output
livestock sector.   The parameters are set arbitrary for simulation and
need not be rigorously exact. The original model solves an optimization
problem (e.g. finding the price or productivity shock that maximizes the
change in revenue) and added several constraints.   But this 2021 version
is limited to computing the change in revenues given some arbitrary price
shocks.

$offtext
```

Explanation of the GAMS program

The GAMS program above is used to implement the model and simulation examples. The GAMS model's ultimate objective is to obtain the changes (in percentage term) in the livestock population following some price shocks[8] and the changes in revenue. A step by step explanation of the program is as follows.

This program starts with the description of three indices or sets:

inputs (capital and labor) indexed i;

outputs (live animals and meat) indexed j;

the arguments or variables cited in the supply functions in Equation (1) (such as price of live animals, past (lagged) price of live animal, input prices etc.) indexed k.

The parameters such as productivity of inputs and the elasticities in the Equation (1) and (2) are then expressed in pdty (i) and the Tables n(j,k) and c(I,j). The initial (i.e. pre-shock) levels of prices Pold(j) and output Xold(j) are also introduced. But the key parameters in the simulation is the table c(j,k) which gives the combination of price shocks that triggers the changes in the supply of livestock and revenue. In other words, the c(j,k) table contains the decision variables that will lead to several scenarios. The initial levels of price Pold and output Xold are also reported in the list of parameters.

Next, the four variables x, x_h, X_{new} and z are formally introduced in the Equation statement and then explicitly written based on:

equation (2): the supply function in growth or percentage terms;

equation (3): the changes in livestock population due to the price shocks;

equation (4): updated level of the number of live animals

equation (6): the change in total revenue;

The last step in the model building is to specify which Equation is to be optimized and under what constraints. The program then orders GAMS to execute the optimization problem, or in this exercise, to compute the values of the changes in the output variables x. xh, and the revenue z.

Test of the Livestock supply model

The model is now used to simulate the livestock supply response to a combination of price shocks. Key to the simulation model and results is having realistic price shock scenarios and, more importantly, having some correct parameter estimates of the technological shift (i.e. the parameter a in Equation (2)) and correct price elasticity parameters (i.e. the α). These parameters are provided by the literature

8 The original model solves an optimization problem (e.g. finding the price or productivity shock that maximizes joint profit or revenue) and adds several constraints. But this version is limited to computing the change in key variables, namely output and revenues given some arbitrary price shocks.

or by a separate econometric study. Similarly, information on initial (i.e. pre-shock) levels of price and quantity is necessary.

A basic example of a scenario of a combination of shocks is described in the GAMS program in Annex 2 and can be summarized here. Appendix Table 2.1 gives the elasticity parameters, i.e. the coefficient of the variables expressed on the right hand side of (2).

Appendix Table 2.1: Elasticity estimates of livestock supply model

	Supply elasticity with respect to:				
	Price of live animal α	Past price of live animal β	Price of meat γ	Rental price of capital δ	Wage σ
Supply of live animals	0.5	0.4	0.1	-0.1	-0.2
Supply of meat	0.4	0.3	0.5	-0.2	-0.4

Next, Appendix Table 2.2 displays the exogenous shocks, i.e. the increases in the key variables whose values are all in percentage terms. In this example, the values of the shocks for the live animal supply equation are identical to those of the meat supply equation, but they need not be necessarily identical.

Appendix Table 2.2: The price shocks in percentage

	% Change in				
	Price of live animal p_l	Past price of live animal (p_{llag})	Price of meat (p_l)	Rental price of capital (r)	Wage (ω)
Supply of live animals	10	15	20	10	5
Supply of meat	10	15	20	10	5

Assuming that the productivity shift is about 1%, the results of the price shocks introduced in Appendix Table 2.2 are summarized in Appendix Table 2.3. The results show that the combination of price shock leads to 12% increase in the supply of live animals and 6.5 % increase in the meat production. More importantly, assuming that the pre-shock unit prices of live animals and of meat are USD 200 and USD 500 on the one hand, and that the pre-shock number of live animals and amount of meat are 1000 and 100 on the other hand, the price shocks have increased the sector's revenue by 22.9 %.

Appendix Table 2.3: Simulation results from test of Livestock Supply Model

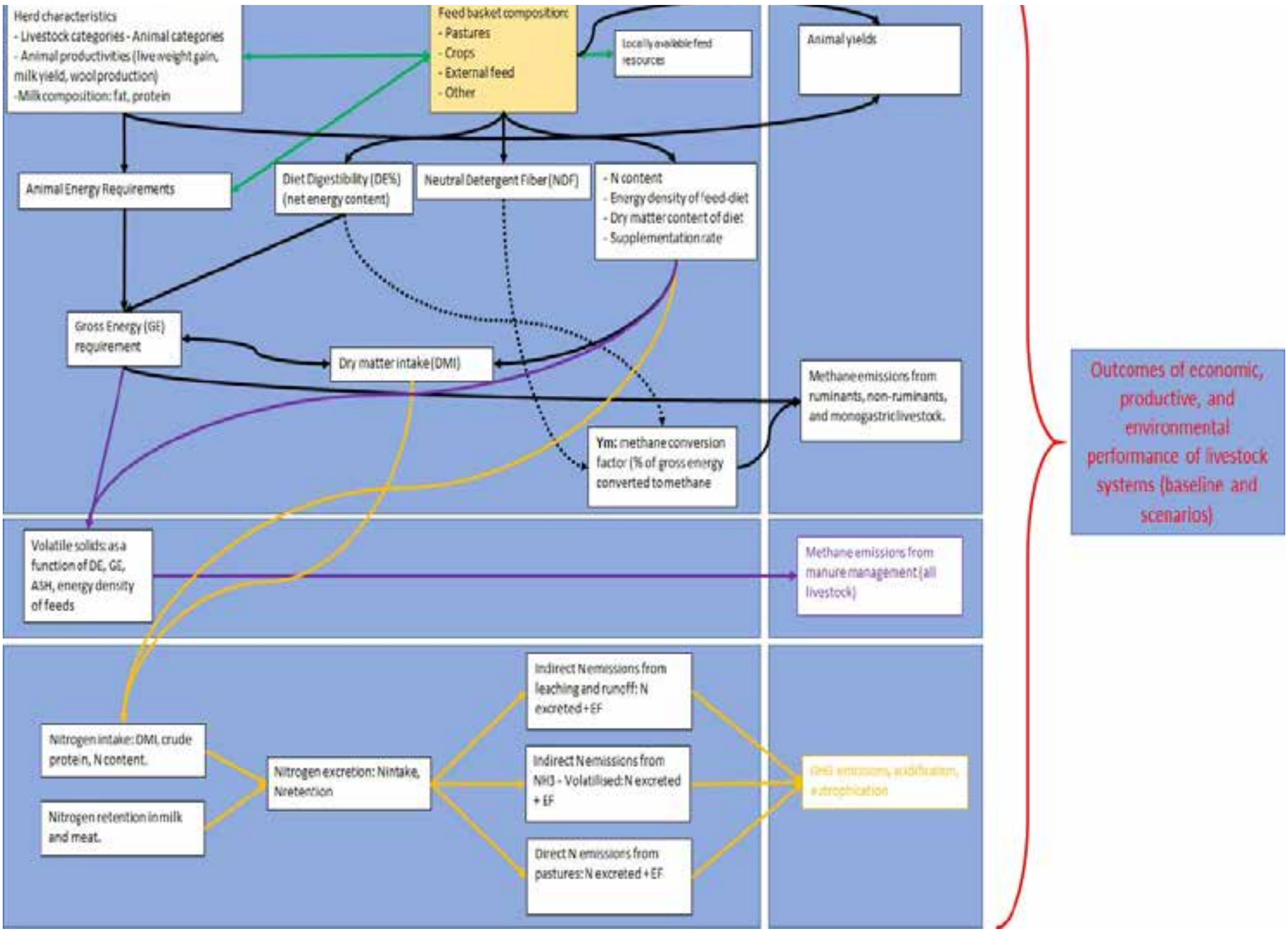
	% Change in output price $(p_{l,m})$	% Change in output volume $(x_{l,m})$	New price level (P) in $per unit	% Change in revenue (z)
Live animals	10	12	220	22.9
Meat	20	6.5	600	

Extensions of the livestock supply model

The Model and GAMS program described above are flexible to changes in the number of sets, variable inputs or outputs. With additional statements, the model can also be used to solve many types of optimization problems with key decision variables such as prices or quantity variables, given a feasible constraint. For instance, expecting some post-pandemic price shocks, the development planner may wish to determine the required growth in outputs (live animal and meat) that meet a desired growth of revenue. In this case, the planner may lay out different scenarios based on various combinations of price shocks, and in each scenario, the program will solve for the required changes in outputs with the constraint that the revenue growth is at least equal to the targeted growth rate.

Appendix 3: Interactions of feed basket with the environmental, economic, and productive performance of livestock systems (conceptual framework)

Appendix 3 Figure 1. Interactions between feed basket composition, herd characteristics, and the derived productive and GHGe effects.



Appendix 4: The Food Security modules

Following an adaptation of Rae and Zhang (2009), the relationship between livestock variables, characteristics of households and food security can be estimated as:

$$\ln\left(FS_{ij}\right) = \alpha_{ij0} + \beta_{1j}LAL_{ij} + \beta_{2j}LND_{ij} + \beta_{3j}HE_{ij} + \beta_{4j}K_{ij} + \beta_{5j}PL_{ij} + \beta_{6j}HS_{ij} + \sum_k \beta_{7kj}ED_{kij} + \sum_k \beta_{8kj}PZ_{kij} + \beta_{9j}LY_{ij} + \beta_{10j}SX_{ij} + \beta_{11j}DS_{ij}$$

where

i and j are the i[th] household and j[th] region, respectively

FS is the indicator of household food security.

LAL is the labor allocated to agriculture and livestock

LND is the number of plots/land available to the household

HE is the household expenditure on a basket of goods (e.g. chicken, beef etc.)

K is the total household opening value of fixed assets (livestock, buildings, plant, and machinery)

PL is the location of household (rural =1, urban=0)

LY is the net income from livestock

HS is the number of household members

ED are the variables for educational qualifications (illiteracy is omitted)

SX is the gender of the household head (male=1, female=0)

DS is the distance of the household location to the market of sales

PZ are the dummy variables for production zones (coastal, and highland, with central zone omitted)

Note: The variables included are based on the LSMS data (NBS 2016). The results section shows the main variables used.

The dependent variable is a measure of food insecurity derived from a variable in the LSMS data, which determines in the last 12 months, whether households have been faced with a situation where they did not have enough food to feed the household. The response which is binary i.e. Yes=0 (food insecure) and No=1 (food secure) is used to construct the logistic regression model.

Regression results

Two versions of the food security model (A and B) are presented below.

- The Prob > chi2 values show they are both good fits.
- The R square values were small compared to the income values but they are less meaningful in logistic regression.
- In model A where individual livestock expenditure is included, only the expenditure on beef is statistically significant and has a negative impact on the dependent variable (food insecurity). This means an increase in household expenditure on beef decrease the chances of a household being food insecure. In other words, beef consumers are less likely to be food insecure. A similar sign is observed for pork and goat but they are not statistically significant. For chicken, the sign is positive.

- In model B, the total household expenditure on livestock is included. Its effect on food insecurity is positive. Thus, households that spend more on livestock consumption are less likely to be food insecure.
- The rest of the household characteristic variables are not statistically significant.

(A) Regression model including expenditures on individual livestock food products

Food Insecurity	Coef.	z	P>z
HH size	0.0049958	0.180	0.600
Gender of HH Head Male	0.1205085	0.380	0.490
Age of HH Head	0.0133999	0.088	0.096
Place Rural	0.6407181	0.092	0.083
Distance to Market	-0.0520306	-1.510	0.090
HH Livestock Income	-0.0622894	-1.510	0.090
Meat Expenditure			
Goat Exp	-0.0000768	-0.850	0.270
Beef Exp	-0.0001095**	-2.330	0.020
Pork Exp	-0.0000404	-0.460	0.450
Chicken Exp	0.0001741	0.086	0.070
Constant	-2.022.032***	-3.09	0.002
R-square	0.0624		

(B) Regression model with aggregated livestock expenditure

Food Insecurity	Coef.	z	P>z
HH size0	0.0085255	0.300	0.530
Gender of HH Head *Male*	0.1479944	0.460	0.450
Age of HH Head	0.0137979	0.090	0.089
Place *Rural*	0.6725674	0.099	0.067
Distance to Market	-0.0404641	-1.180	0.170
HH Livestock Income	-0.0508937	-1.380	0.120
Total Expenditure on Livestock	-0.0001268*	-2.260	0.024
Relative Livestock Expenditure	1.779.758	1.410	0.110
Constant	-2.185.143**	-3.300	0.001
R-square	0.0533		

References for Appendix 4

NBS. 2016. 2014/15 Annual Agricultural Sample Survey Report. National Bureau of Statistics. Tanzania: NBS. 1–69.

Rae, A. N. and Zhang X. 2009. China's booming livestock industry: household income, specialization, and exit. *Agricultural Economics* 40(6):603–16. doi: 10.1111/j.1574-0862.2009.00402.x.

Appendix 5: The gender impacts module

The Gender post-solution module adapts the approach to food security calculations derived from Robinson et al. 2015 and reported in Appendix 3. It makes use of relationships, established using statistical methods, of gender and livestock-related indicators. In its basic form, the gender-differentiated derivation is represented as follows.

(A5.1) $$\Delta GI_{q,t,t0} = A + \left(a * ln \frac{L_{q,t}}{L_{q,t0}}\right) + (b * \Delta NL1_{q,t,t0}) + (c * \Delta NL2_{q,t,t0}) - (d * \Delta NL3_{q,t,t0})$$

In one application, we have linked gender-differentiated impacts to household incomes, with gender of the household head affecting incomes of livestock-keeping households. Following Rae and Zhang (2009), the relationship between livestock variables, characteristics of households and per capita income has been estimated as:

(A5.2)

where

Y is the household net income per capita earned in the year prior to the survey.

LAL is the labor allocated to agriculture and livestock

LND is the number of plots/land available to the household

HE is the household expenditure on a basket of goods (e.g. chicken, beef etc.)

K is the total household opening value of fixed assets (livestock, buildings, plant, and machinery)

PL is the location of household (rural =1, urban=0)

LY is the net income from livestock

HS is the number of household members

ED is the level of education of the household head

SX is the gender of the household head (male=1, female=0)

DS is the distance of the household location to the market of sales

PZ is the production zone where households are based (central zone omitted)

Note: The variables included are based on the LSMS data as well as their impact/significance in the model. The results section shows the main variables used

Model modification

Because we want to have a variable through which intervention in the livestock sector could be assessed, we derived total household income from livestock and included it as an explanatory variable. The reasoning is that households' livestock income is influenced by market prices of live or slaughtered animals. Establishing a significant and positive relationship between per capita income and livestock earning means that we can assess the effect of a livestock sector intervention that affects the market prices of livestock-derived food products.

Next, we have included household consumption expenditure as an explanatory variable. The household expenditure is the total cost of baskets of consumer products.

The household expenditure has two components: 1) total expenditure on livestock products and 2) livestock expenditure relative to all other household consumption goods. Here it is expected that an intervention in the livestock sector that impacts market prices of livestock products will impact consumption expenditure of those products. This implies that depending on whether the household is a net consumer or net producer of specific livestock products, such interventions could impact their per capita income negatively or positively, respectively.

The table below summarizes the main types of household livestock consumption and their sources as captured by the LSMS data.

	CONSUMPTION IN PAST DAYS		SOURCE	
MEAT TYPE	*YES*	*NO*	*OWN PRODUCTION*	*PURCHASE*
Goat meat	86	1,098	19	67
Beef including minced	420	764	20	400
Pork including sausage	49	1,135	1	48
Chicken and other poultry	206	978	114	92

Regression results

- Three versions of the income models (A, B and C) are presented below with the differences being the explanatory variables included or excluded.
- The model shows a good fit with F-value significant at 1% level for all three versions
- The R-square values show a reasonable model fit.
- Household size is statistically significant for most of the models estimated and its negative sign is consistent with reviewed studies.
- Earning income from livestock significantly affects the household per capita income. The sign was positive indicating that, an increase in the earnings from the livestock sector significantly raises the general income levels of household members.
- Household expenditures on livestock products are not statistically significant. The sign of its effect on per capita income is mixed with some products showing negative and others showing positive.
- In Model A where the individual livestock expenditures are included, only beef expenditure shows a positive effect on per capita income. Consumption expenditures on goat, chicken and pork all have negative effects on per capita income.
- In Model B where relative livestock expenditure is included, it has a negative impact on per capita income. This means the increase in consumption of livestock products relative to other consumption goods decreases the per capita income. However, this variable is not statistically significant.
- Adding household labour, assets, partial livestock productivity, number of plots, and a production zone dummy does not significantly change the results.
- Level estimates provide a better model fit than a model of the natural logarithms. In addition, the logarithm model leads to a reduced sample size.

A) Regression model with individual livestock expenditures

Per Capita Income	Coef.	t	P>t
HH size HH size	-21147.24**	-2.52	0.012
Gender of HH Head			
Male	-53751.24	-0.59	0.380
Age of HH Head	-372.85	-0.16	0.610
Place			
Rural	-171140	-1.86	0.064
Distance to Market	2.320.106	0.47	0.450
HH Livestock Income	.5760714***	11.30	0.000
Meat Expenditure			

Per Capita Income	Coef.	t	P>t
Goat Exp	-1.051.258	-0.43	0.46
Beef Exp	1.350.516	1.13	0.18
Pork Exp	-7.259.522	-0.26	0.55
Chicken Exp	-.7954992	-0.02	0.68
Relative Livestock Expenditure	-16697.78	-0.05	0.67
Constant	486890.2***	0.134	0.007
R-square	0.2958		

B) Regression model expressing livestock expenditures relative to other household consumption

Per Capita Income	Coef.	t	P>t
HH size	-29451.73**	-2.790	0.006
Gender of HH Head *Male*	-36128.93	-0.370	0.500
Age of HH Head	1.803.14	0.047	0.350
Education of HH Head	9298.64	1.150	0.180
Place *Rural*	-121600.80	-1.190	0.160
Distance to Market	3.035.99	0.043	0.370
HH Livestock Income	.97274***	0.594	0.000
Total Expenditure on Livestock	4.375.77	0.370	0.500
Relative Livestock Expenditure	-124248.8	-0.360	0.500
Constant	197696.2	0.056	0.300
R-square	0.2930		

C) Regression model with reduced variables on household characteristics

Per Capita Income	Coef.	t	P>t
HH size	-20649.42**	-2.49	0.013
Gender of HH Head *Male*	-56028.78	-0.63	0.370
Age of HH Head	-2.989.58	-0.13	0.620
Place *Rural*	-184213.8	-2.03	0.043
Distance to Market	2.028.916	0.420	0.470
HH Livestock Income	0.5738992***	11.38	0.000
Total Expenditure on Livestock	6.657.736	0.060	0.270
Constant	489404.9**	0.139	0.005
R-square	0.2930		

References for Appendix 5

Rae, A. N. and Zhang X. 2009. China's booming livestock industry: household income, specialization, and exit. *Agricultural Economics* 40(6):603–16. doi: 10.1111/j.1574-0862.2009.00402.x.

Robinson, S., Mason d'Croz, D., Islam, S., Sulser, T. B., Robertson, R. D., Zhu, T., Gueneau, A., Pitois, G. and Rosegrant, M. W. 2015. The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description for Version 3. IFPRI Discussion Paper 01483. 1483. Washington, DC.

Appendix 6: Parameter descriptions and data sources

Parameter name (in the model)	Description	Unit of Measurement	Sources of Data for Parameter Estimation
CONV(C)	Conversion ratio of farm weight to product weight	-	Tanzania LSIPT1
PMARGPR(C)	Processing cost as a fraction of consumer prices	-	Wilson and Lewis (2015); Musa (2019)
CTA(C)	Commodity transportation cost adjustment factor	-	Calculated, based on Mkenda and Van Campenhout (2011)
XPROC(C)	Extra cost of processing cattle for export	Tanzania Shillings (Tsh) per kg	Tanzania LSIPT 1
FEEDCONV(C)	Feed conversion, i.e. aggregate feed per unit of meat produced	-	Tanzania LSIPT1 prepared by CIRAD
AREA0(F,R,U)	Crop area for urban-rural consumption in 2015 of the major crop used as feed in cattle production	1000 Ha	2014/15 Annual Agricultural Sample Survey (AASS) report
YIELD0(F,R,U)	Yield of the major crop for consumption by the urban and rural population in 2015	Tons per ha	2014/15 AASS report
PROD0(C,R,U)	Crop & cattle production for urban-rural consumption in 2015	1000 tons	2014/15 AASS report
CRPROD0(C,R,U)	Crop production for urban and rural consumption in 2015	1000 tons	2014/15 AASS report
LVPROD0(C,R,U)	Livestock production for urban and rural consumption in 2015	1000 tons	2014/15 AASS report
DPC0(C,R,U)	Per capita food consumption in 2015	Kg per year	2012 Population and Housing Census; 2014/15 AASS Report
PD0(C,R,U)	Consumer price in 2015	Tsh per kg	2014/15 AASS report
PDB(C,R,U)	Base scenario consumer prices	Tsh per kg	Regional reports; LSMS Wave 4 report; 2016/17 AASS report
PW0(C,*)	Commodity world price in 2015	US$ per ton	FAOSTAT
TRADE(C,*)	Import and export volumes in 2015	1000 tons	NBS Tanzania National Food Balance Sheets 2014 – 2017 Report
IDEN1(C,F)	Identity matrix of feed demand inflows	-	
IDEN2(C,L)	Identity matrix of livestock Supply outflows	-	
KM(RW,RRW,*)	Distance from regions to country borders (for world trade)	km	Direct Google search; Globefeed
YPC0(R,U)	Urban & rural per capita income in 2015	Million Tsh per year	National Accounts Statistics of Tanzania Mainland 2012 – 2018 report
POP0(R,U)	Urban & rural population in 2015	1000 residents	NBS Population and Housing Census; NBS National Population Projections 2018 report
FEEDSHARE(L,F)	Share of feed-in composite feed demand by animal type	Fraction	Tanzania LSIPT1
ADJ(C,*)	Adjustment factor matching Tanzania LSMS consumption data to with national statistics	-	

Parameter name (in the model)	Description	Unit of Measurement	Sources of Data for Parameter Estimation
YGR(R,U)	Projected annual income growth 2015-25	Percent	Regional GDP growth projections data from the Tanzania National Accounts Statistics
PGR(R,U)	Projected annual population growth 2015-25	Percent	NBS National Population Projections 2018 report
AREAE(F,R)	Elasticity of crop area with respect to output prices	-	2014/15 AASS report
YIELDE(F,R)	Elasticity of crop yield with respect to output prices	-	2014/15 AASS report
LVELAS(L,LL,R)	Elasticity of livestock supply with respect to output prices	-	2014/15 AASS report
LVFDEL(L,F)	Elasticity of livestock supply with respect to feed prices	-	2014/15 AASS report
DYE(C,R,U)	Food demand elasticity with respect to consumer income	-	Calculated, based on 2014/15 AASS report
DPE(C,CC,R,U)	Food demand elasticities with respect to food prices	-	Calculated, based on 2014/15 AASS report
FDELAS(F,F)	Elasticity of feed demand with respect to feed own prices	-	Tanzania LSIPT1
PWGR(T,C)	Annual Growth Rate of World Commodity Price	Percent	World Bank Commodity Markets Outlook
TAX0(C,*)	Taxes in 2015	Percent	Tanzania Business Portal, Ministry of Industry and Trade (MITI)
DFOOD0(C,R,U)	Original food demand in 2015	1000 tons	Calculated, based on 2014/15 AASS report
DFEED0(C,R,U)	Original feed use for producing meat consumed domestically	1000 tons	Tanzania LSIPT1
DFEED0(C,R,U)	Original total maize consumption by humans and animals	1000 tons	Calculated, based on 2014/15 AASS report and Tanzania LSIPT1

1http://www.fao.org/3/ca7635en/CA7635EN.pdf

Appendix 7: The QUAIDS model used in the Demand Analysis

The QUAIDS is specified as follows:

(A7.1) $$w_i = \alpha_i + \sum_j \gamma_{ij} \ln(P_j) + \beta_i \ln\left[\frac{E}{a(P)}\right] + \frac{\theta_i}{b(P)} ln\left[\frac{E}{a(P)}\right]^2$$

Where:

(A7.2) $$lna(P) = \alpha_0 + \sum_i \alpha_i \ln(P_i) + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln(P_i)\ln(P_j)$$

And

(A7.3) $$b(P) = \prod_i P_i^{(\theta_i)}$$

Where w_i is the budget share for the food commodity i among the S&ASF commodities; E is the total expenditure on S&ASF; while α_o, α_i, β_i, θ_i and γ_{ij} are parameters to be estimated. From economic theory, the following restrictions the parameters of the budget share equations apply:

Adding up: $\sum_i \alpha_i = 1$; $\sum_i \gamma_{ij} = 0$; $\sum_i \beta_i = 0$;

Homogeneity: $\sum_j \gamma_{ij} = 0$; and;

Slutsky Symmetry: $\gamma_{ij} = \gamma_{ji}$

Following Ray (1983) and Poi (2002) and Poi (2012), a vector of s variables representing the demographic characteristics of households is included in the estimation, and equation 1 be written as:

(A7.4) $$w_i = \alpha_i + \sum_j \gamma_{ij} \ln(P_j) + (\beta_i + \eta_i'\boldsymbol{Z}) \ln\left[\frac{E}{\bar{E}_0(Z)a(P)}\right] + \frac{\theta_i}{b(P)c(P,Z)} ln\left[\frac{E}{a(P)}\right]^2$$

Where $$c(P,Z) = \prod_{j=1}^{k} p_j^{\eta_j' Z}$$

(A7.5) $$c(P,Z) = \prod_{j=1}^{k} p_j^{\eta_j' Z}$$

Z represents a vector of demographic characteristics and the parameters associated with them. $\bar{E}_0(Z)$ measures the increase in household expenditure as a function of Z, not controlling for any changes in consumption patterns. The adding-up condition requires that $\sum_{j=1}^{k} \eta_{rj} = 0$

The uncompensated price elasticity of good i with respect to changes in the price of good j is:

(A7.6) $$\in_{ij} = -\delta_{ij} + \frac{1}{w_i}\left(\gamma_{ij} - \left[\beta_i + \eta_i' Z + \frac{2\theta_i}{b(P)c(P,Z)} ln\left\{\frac{E}{E_0(Z)a(P)}\right\}\right] * \left(\propto_j + \sum_j \gamma_{ij}\, lnP_j\right) - \frac{(\beta_j + \eta_i' Z)\theta_i}{b(P)c(P,Z)}\left[ln\left\{\frac{E}{E_0(Z)a(P)}\right\}\right]^2\right)$$

The expenditure elasticity for commodity i is:

(A7.7) $$\mu_i = 1 + \frac{1}{w_i}\left[\beta_i + \eta_i' Z + \frac{2\theta_i}{b(P)c(P,Z)} ln\left\{\frac{E}{\bar{E}_0(Z)a(P)}\right\}\right]$$

Compensated price elasticities are obtained from the Slutsky equation**:**

(A7.8) $$\in_{ij}^{C} = \in_{ij} + \mu_i w_j$$

References for Appendix 7

Poi, B. P. 2012. Easy Demand-System Estimation with Quaids. ***The Stata Journal*** 12(3):433–46.

Appendix 8: Pilot test using Tanzania data

Appendix Table 8.1 presents the model's projections of beef supply over a 12-year period starting in 2016 (the selected base year).

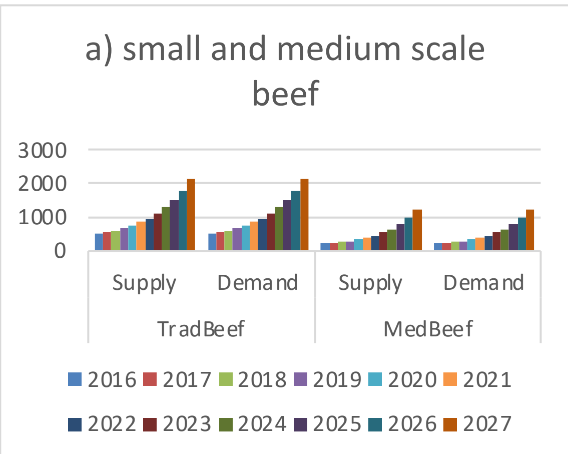
Appendix Table 8.1: Total beef supply from regions included in the modelling

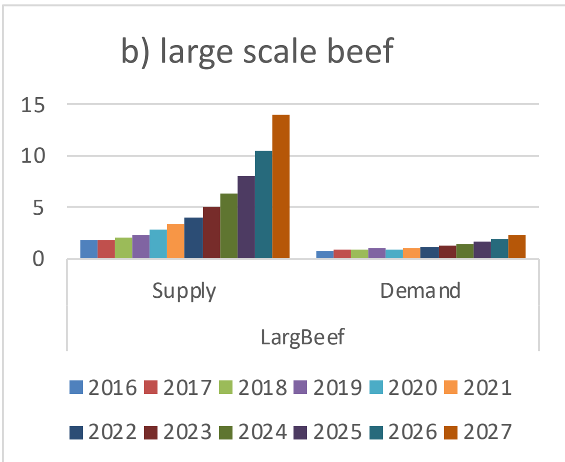
	GEI	MAN	MAR	MBE	MWA	SHI	TAB	Total
2016	81.01	116.34	136.70	81.16	92.94	112.33	107.92	728.40
2017	96.17	128.98	136.79	81.18	89.55	117.47	108.98	759.11
2018	124.85	154.44	146.51	85.93	92.33	132.32	117.59	853.98
2019	154.09	179.25	152.11	88.72	91.84	143.54	122.64	932.19
2020	206.33	222.83	167.80	96.94	97.37	166.63	136.09	1094.00
2021	257.99	263.94	177.33	101.98	98.11	183.63	143.93	1226.91
2022	329.72	319.54	191.08	109.35	100.69	206.50	155.03	1411.91
2023	423.19	389.42	207.45	118.15	103.83	233.66	167.87	1643.56
2024	545.51	477.68	226.92	128.64	107.60	266.07	182.76	1935.19
2025	706.36	589.79	250.12	141.17	112.08	304.94	200.07	2304.54
2026	917.27	731.62	277.50	156.08	117.17	351.45	220.04	2771.13
2027	1196.66	913.93	310.31	173.91	123.18	407.74	243.38	3369.12

GEI: Geita; MAN: Manyara; MAR: Mara; MBE: Mbeya; MWA: Mwanza; SHI: Shiyanga; TAB: Tabora

According to the model results, the total demand for beef from small-scale operations is projected to grow more than 315%, from 511,000 MTs in 2016 to nearly 2.13 million MTs in 2027 (Appendix Figure 8.1). Demand from medium scale operations increases by nearly 470% over the same period. The supply of these two beef types/sources is projected to grow at similar rates so that their demand and supply remain closely matched. Beef from large-scale operations (likely sold as chilled or frozen meat products), while accounting for a small proportion of the total beef production in both 2016 (0.24%) and 2027 (0.42%), sees a big increase between both years.

Appendix Figure 8.1: Projected growth in beef supply and demand for a) small and medium scale and b) large scale beef production, from 2016 to 2027





Beef supply from large scale operations increases by 700% between 2016 and 2027. In relative terms, i.e. meat from large scale operations doubles its share of the total beef supply. As the demand for this beef product within the seven regions grows at a slower rate (i.e. 222% over the period), much of the produced beef from the large systems is assumed sold to other regions or traded internationally.

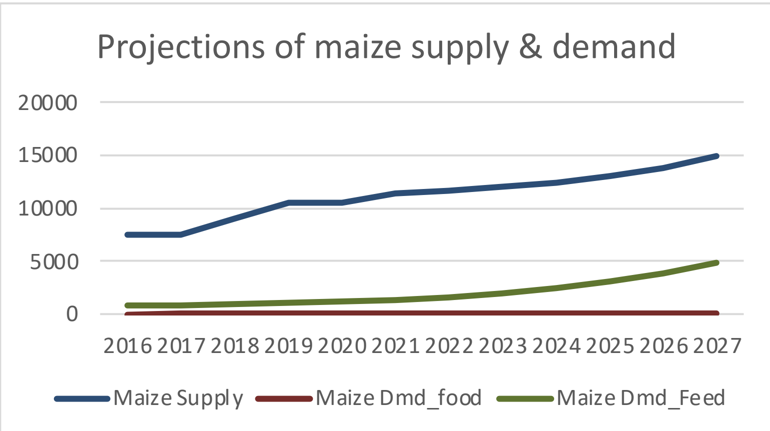
In the case of maize, supply is projected to grow by 98% between the initial and final simulation years (Appendix Table 8.2). Food demand for maize is projected to grow 204%, while maize feed demand will grow 557%. However, supply quantities for the selected regions far exceed demand quantities (for both feed and food, see Appendix Figure 8.2), suggesting that the selected region is a net producer with respect to maize and will use maize for other purposes, export maize to other regions of Tanzania or trade it internationally. We have not included the pilot test results on exports.

Appendix Table 8.2: Total maize supply from regions included in the modelling

	GEI	MAN	MAR	MBE	MWA	SHI	TAB	Total
2016	528.6	229.7	17.7	1803.8	2890.2	108.2	1928.9	7507.3
2017	534.8	235.2	18.3	1827.1	2861.3	111.2	1949.6	7537.4
2018	596.1	237.2	16.8	2015.3	3816.0	109.1	2190.5	8980.9
2019	661.5	246.7	16.5	2220.8	4748.4	111.4	2443.8	10449.1
2020	691.9	251.6	19.0	2335.3	4548.6	124.2	2545.5	10516.0
2021	755.5	278.8	21.4	2554.4	4827.6	138.4	2775.9	11352.0
2022	811.0	319.1	26.2	2762.2	4576.0	162.4	2963.2	11620.0
2023	879.7	373.7	33.3	3022.1	4270.0	195.8	3194.0	11968.6
2024	963.7	447.8	44.0	3343.4	3909.3	242.6	3475.1	12426.0
2025	1065.4	549.4	60.4	3737.3	3495.5	309.2	3814.7	13031.8
2026	1158.6	687.6	83.5	4126.7	3227.3	413.4	4112.1	13809.2
2027	1308.4	883.6	123.4	4638.4	2821.7	562.9	4527.2	14865.6

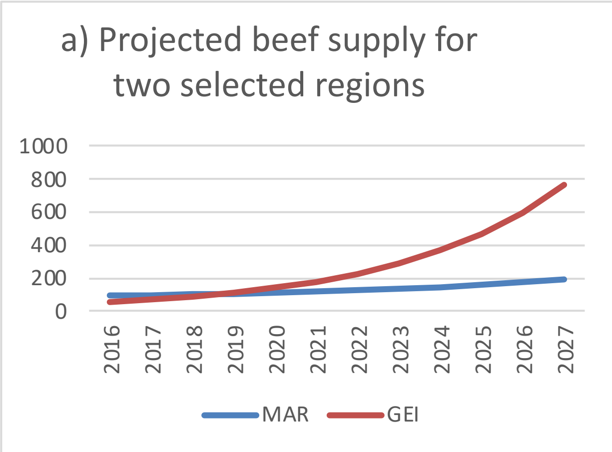
GEI: Geita; MAN: Manyara; MAR: Mara; MBE: Mbeya; MWA: Mwanza; SHI: Shiyanga; TAB: Tabora

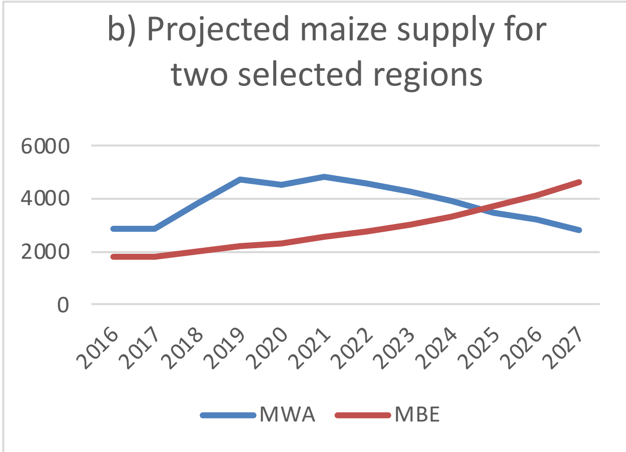
Appendix Figure 8.2: Projected quantities of maize supply and demand for food and livestock feed use, from 2016 to 2027 (1000 MTs)



The model also allows the assessment of the regional trends in livestock and feed demand and supply separately. In the regions included in the analysis, Mara accounts for the highest proportion (19%) of volume produced of traditional beef by the seven selected regions in 2016 but is down to a 9% share of the production in 2027 (Appendix Figure 8.3). On the other hand, the Geita region, which accounts for only 11% of traditional beef production in 2016, leads in 2027 with a 36% share of the production. In the case of maize, Mwanza accounts for nearly 40% of maize production by the seven regions but for 19% in 2027, while Mbeya, the regional leader in maize production in 2016 (31%), produced less than 25% in 2016.

Appendix Figure 8.3: Projected supply of (a) beef and (b) maize for selected regions, from 2016 to 2027 (1000 MTs), highlighting the switching importance of regions in total production.





Expansion of the multimarket model to include sheep, goats, pigs, and chickens showed poultry to account for 38% of all meat (ruminant and monogastric) production in 2016 while beef had a 36% share of the production in 2016 (see Appendix Table 8.4). Goat and sheep production is of relative importance (at 18% and 6%, respectively), while pig production is of minor importance (2%). Generally, ruminant meat is 60% of all meat production, with monogastrics (i.e. pigs and chickens) providing the rest of meat production. On the consumption side, the demand for poultry is around 55% of all meat demand in the seven regions; beef demand is 18%, goat demand is 17%, pig demand 8%, and sheep demand less than 1% (not included in the table below). The results suggest that while meat production (in the 7-sample regions) is almost equally dominated by beef and chicken (36% and 38%, respectively), demand for meat in the region is heavily dominated by poultry. In addition, sheep is more important to production than it is as a consumption item, while the opposite holds for pig demand and supply.

Appendix Table 8.3: Meat production in (7) test case Tanzania regions - quantities

	Beef	Goat	Sheep	Pig	Poultry	All Meat
	Supply in 1,000 MTs					
MWA	835.4876	364.8432	151.084	10.62903	848.1876	2210.231
SHI	753.8316	296.7418	105.4872	21.12525	851.1494	2028.335
MBE	656.558	280.0488	85.0844	248.2099	1117.289	2387.19
TAB	1097.868	579.2012	176.694	68.64728	1060.511	2982.922
MAR	755.0368	357.4832	169.1324	1.057342	702.828	1985.538
MAN	864.6872	609.8292	248.958	1.215184	486.2184	2210.908
GEI	652.4488	271.3576	32.9588	3.95604	831.3276	1792.049
TOTAL	5615.918	2759.505	969.3988	354.8401	5897.512	15597.17

Appendix Table 8.4: Meat production in (7) test case Tanzania regions - percentages

	Beef	Goat	Sheep	Pig	Poultry
	Supply as % of total production				
MWA	38%	17%	7%	0%	38%
SHI	37%	15%	5%	1%	42%
MBE	28%	12%	4%	10%	47%
TAB	37%	19%	6%	2%	36%
MAR	38%	18%	9%	0%	35%
MAN	39%	28%	11%	0%	22%
GEI	36%	15%	2%	0%	46%
TOTAL	36%	18%	6%	2%	38%

The dynamics revealed by the pilot test will be verified and updated following an ongoing data and model validation exercise.

ISBN: 92–9146–701–4

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