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The Dynamic Impacts of Alternative Livestock Sector Intervention and Spending Options in Rwanda

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1 ABSTRACT

This study evaluates the cost-effectiveness of various livestock interventions—feed, breeding, and health—and budget allocation strategies (balanced, feed-oriented, breeding-oriented, and health-oriented) in the context of Rwanda’s economic and livestock systems. Using an economic and livestock systems integrated framework, the research highlights moderate yet sustained impacts on agricultural Gross Domestic Product (GDP) and significant improvements in the livestock sector. Overall, breeding interventions have the largest cumulative effect on agricultural GDP, while health measures, particularly dewormers, yield long-term gains in livestock productivity. Under the balanced scenario, breeding contributes significantly to both meat and milk sector GDP, while feed interventions show a smaller impact overall. The study also finds that biased spending scenarios lead to differing outcomes across livestock sub-sectors. Breeding-oriented spending boosts milk GDP initially, whereas health-oriented spending excels in meat production through reduced deaths and increased liveweight. By the end of the simulation period, a balanced investment strategy results in a 12.5 percent increase in meat yield and a 27 percent rise in milk yield, largely driven by breeding. Health interventions, particularly deworming, are crucial for sustained meat production, while improved feed mitigates mortality and supports stock growth. These results can support policy dialogue, such as the recently introduced Fifth Strategic Plan for Agriculture Transformation (PSTA 5), as policy makers seek to revitalize the livestock sector and enhance its resilience to future challenges.

Key words: Economywide model, livestock system, interventions, spending options, dynamic impact, Rwanda

2 INTRODUCTION

Globally, the livestock sector plays a vital role in agricultural development, food production, and nutrition security, contributing 33 percent of human protein consumption and 17 percent of total caloric intake (FAO 2018). Nearly 1 billion smallholder livestock producers in developing countries rely on this sector, which accounts for 40 percent of agricultural Gross Domestic Product (GDP) and contributes between 2 to over 33 percent of household incomes (Alders et al. 2021). With the global population rapidly increasing, especially in developing regions where rural poverty and hunger are prevalent, the livestock sector is under significant pressure to perform efficiently and meet the growing demand for food.

Over time, the livestock sector has been evolving, particularly in the developing world, in response to rising incomes (Thornton 2010, Boden et al. 2015), dietary shifts (Popkin 2003), urbanization (Hatab et al. 2019; Latino et al. 2020), and climate change (Heinke et al. 2020, Thornton et al. 2006). This transition has been driven by advancements in science and technology, along with increases in animal numbers. However, production growth has not kept pace with rising demand, leading to higher prices, which in turn has constrained household consumption of animal-sourced foods (ASF) (Daba et al. 2024). Continued advancements in breeding techniques, feed availability, and animal health will be crucial for increasing production and improving efficiency (Bai et al. 2018, Thornton 2010).

While significant progress has been made, this situation is also reflected in Rwanda. With a rapidly growing population, increasing urbanization, and rising incomes, the demand for ASF is expected to rise significantly in the foreseeable future. In response, the government and various development agencies have implemented several strategies to promote the sector and enhance its resilience (Shapiro et al. 2017, MINAGRI 2018). However, these measures have not been fully evaluated in terms of their effectiveness in improving sector performance, nor have they been compared against one another for their broader impact on the sector and beyond. In this context, the present study assesses the effectiveness of various – feed, breeding, and health related – livestock sector interventions in sustaining farm incomes, food security, and welfare.

This paper contributes to the analysis of public spending on the Rwandan livestock sector in several critical ways. First, we employ a dynamic integrated economic and animal systems model called LEAS (Linked Economic and Animal Systems model) (Aragie et al. 2021) to examine the dynamic impact of alternative livestock sector interventions in Rwanda in the context of the wider economy. Unlike most studies, which focus exclusively on either the crop or livestock sector (Hasegawa et al. 2020; Schierhorn et al. 2020, Bernabucci, 2019, Acosta et al. 2021), our approach captures the interdependence of these sectors within an economywide framework, providing a more comprehensive understanding of their interactions. Second, we evaluate various livestock sector interventions in terms of their relative cost-effectiveness in achieving targeted economic outcomes. Third, we not only assess the relative impacts of these measures but also compare alternative budget allocation options (balanced, feed-oriented, breeding-oriented, and health-oriented) in relation to selected indicators, examining their overall effects on both the economic and livestock systems. This holistic assessment of interventions and spending options aims to guide policymakers in revitalizing the livestock sector for greater impact.

The importance of public spending in addressing constraints within the agricultural sector is well-documented in the literature. Studies such as Aragie and Balie (2019), Arndt et al. (2016), and Pham and Riedel (2019) emphasize the significance of policy and budget support for promoting inclusive rural transformation. Others, including Aragie et al. (2024), Benfica et al. (2019), and Pauw and Thurlow (2015), explore the comparative effectiveness of policy reforms and investment strategies for fostering growth, poverty reduction, and improved diet diversity. While these studies offer valuable perspectives, our research advances this body of knowledge by situating livestock herd dynamics within an economywide framework. We analyze the adjustment dynamics of the economic and livestock systems in response to specific interventions, while also exploring their welfare implications in a lower-income economy context. By employing a framework that integrates both economic and livestock systems, our study offers fresh insights, particularly for Rwanda—a country with limited existing literature on the subject.

The rest of the paper proceeds as follows. First, we provide an overview of the Rwanda's livestock sector in the context of the rest of the economy, as well as the distribution of cattle, sheep and goats by livestock system. Second, we outline the analytical method used to evaluate the impact of alternative intervention and spending options for Rwanda. This section presents the theoretical framework that details various pathways of the impact of livestock interventions on the sector's performance and presents the integrated economic and animal system model that is used to generate key outcome indicators. The third section introduces the scenario design with reference to the benchmark trajectory along with the intervention and spending scenarios considered. The results section presents findings from both the economic model and the animal systems model. Finally, we summarize the key conclusions drawn from this study.

3 THE NATURE OF RWANDA'S LIVESTOCK SYSTEM

Endowed with a population of over 14 million, Rwanda is home to 11.4 million people directly relying on agriculture as a source of livelihood (World Bank 2024). In 2020, there were about 2.3 million farm households engaged in some sort of farm practices, of which 78 percent are engaged in crop production, 61 percent are engaged in livestock rearing, with about 74 percent practicing both (NISR 2021). In Rwanda, poverty remains pervasive, with 36.7 percent of the population living below the national poverty line as of 2017 (NISR 2018), most of whom reside in rural areas.

Broadly speaking, Rwanda's dominant agricultural system comprises mixed agriculture, which accounts for 17.4 percent of GDP, and is characterized by integrated crop and livestock production (Table1). The livestock sector contributes over 14.4 percent of the sector's gross output, while crops account for 59.5 percent. Within livestock, the largest value added is generated by the cattle and milk sector which accounts for about 69 percent of the total. Approximately 14.6 and 26.4 percent of primary livestock and crop output is consumed domestically by semi-subsistence farm households, without reaching the market.

Table 1: The contribution of primary livestock in Rwanda (bil. RWF)

	Gross output (bil. RWF)	Share of own consumption (%)
Overall output	16.88	8.1
Agriculture	2.95	4.4
Crop	1.75	26.4
Livestock	0.43	14.6
Cattle and milk	0.30	13.1
Sheep and goat	0.04	0.0
Poultry and eggs	0.06	35.4
Others	0.03	8.0
Forestry and Fishing	0.77	86.5

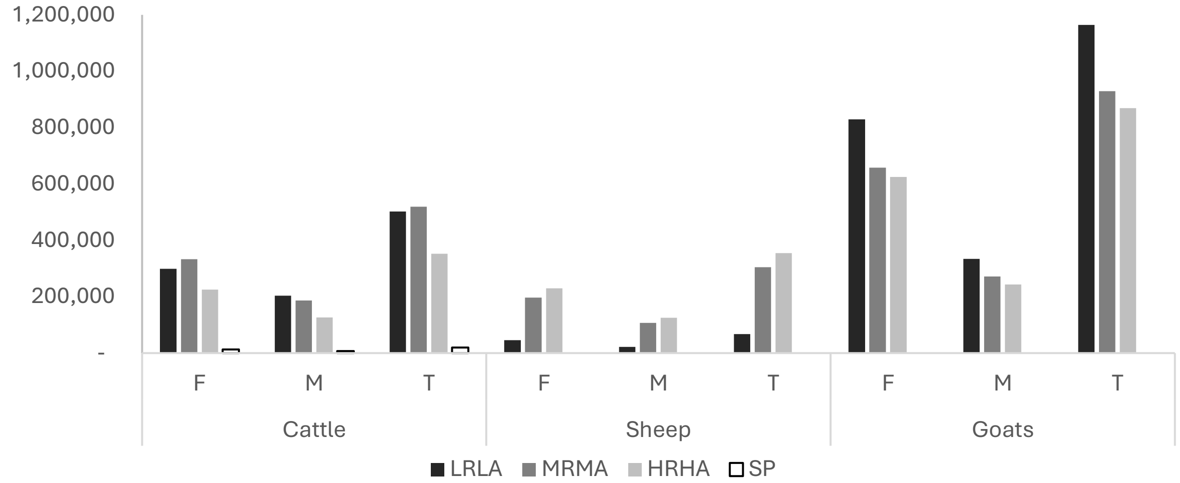
Note: Gross output is in billion Rwandan Francs (RWF).
Source: IFPRI et al. (2022)

Rwanda's livestock sector comprises a wide variety of animals, with poultry, cattle, sheep, and goats being the most prominent (Shapiro et al. 2017). Studies show diversity in distribution of animals across the standard livestock systems identified in Rwanda: (a) the Low Rainfall Low Altitude (LRLA) zone which predominantly covers the eastern savanna and the eastern plateau of Rwanda; (b) the Medium Rainfall and Medium Altitude (MRMA) zone which is predominantly found in the central plateau; (c) the High Rainfall High Altitude (HRHA) which covers the western highland, Lake Kivu and South West regions, and (d) the Specialized Production (SP) system with their unique modern production characteristics and commercial orientation.

Detailed disaggregated livestock data is unavailable in Rwanda. Therefore, disaggregating research projections are combined to make estimates of Rwandan livestock sex and age for our model. Using information from FAO (2023), initial livestock demographic parameters from the Livestock Master Plan (LMP) (Shapiro et al. 2017) and the 2020 Agricultural Household Survey data (NISR 2021), and a cross-entropy technique of data estimation (Xavier et al. 2014; Robinson et al. 2000), we disaggregate Rwanda's data in a way usable to calibrate the modeling framework adopted in this study.[1] Figure 1 shows the distribution of cattle and small ruminants (sheep and goats) by livestock system in Rwanda. Approximately two-thirds of Rwanda's 1.4 million cattle population is concentrated in the LRLA and MRMA zones, each constituting a comparable share. Goat distribution follows the same pattern. By contrast, close to half of the sheep are in HRHA, with only 10 percent residing in LRLA.

[1] The cross-entropy technique employed for disaggregating livestock data by age and sex utilizes a standard herd dynamics module (HDM). This method incorporates time series data on livestock numbers, as well as milk and meat production levels, alongside initial placeholder values for various livestock parameters, including death rates, birth rates, offtake rates, and yields. The approach then solves for the age distribution and demographic parameters that are consistent with the stock and production (meat and milk) data.

Figure 1: Baseline number of cattle, sheep, and goats by livestock system in Rwanda



Note: LRLA: Low Rainfall Low Altitude zone, MRMA: Medium Rainfall and Medium Altitude zone, HRHA: High Rainfall High Altitude zone, and SPEC: Specialized Production zone. F=Female, M=Male, T=Total.
Source: Rwanda Linked Economic and Animal Systems (LEAS) model

The livestock sector in Rwanda has been encountering significant challenges attributed to weather shocks, leading to notable and recurrent declines in animal numbers. Analysis of livestock time series data spanning from 2000 to 2021 (FAO 2024) indicates that the country experienced three major shocks, showing declines in stock ranging from 4 to 14 percent in magnitude at the national level. Low productivity is also indicative of the livestock sector in Rwanda (Shapiro et al. 2017). This calls for thoughtful investment and development plans aiming at unlocking key constraints to the sector, including increasing access to quality feed, veterinary services, and breeding and genetic interventions.

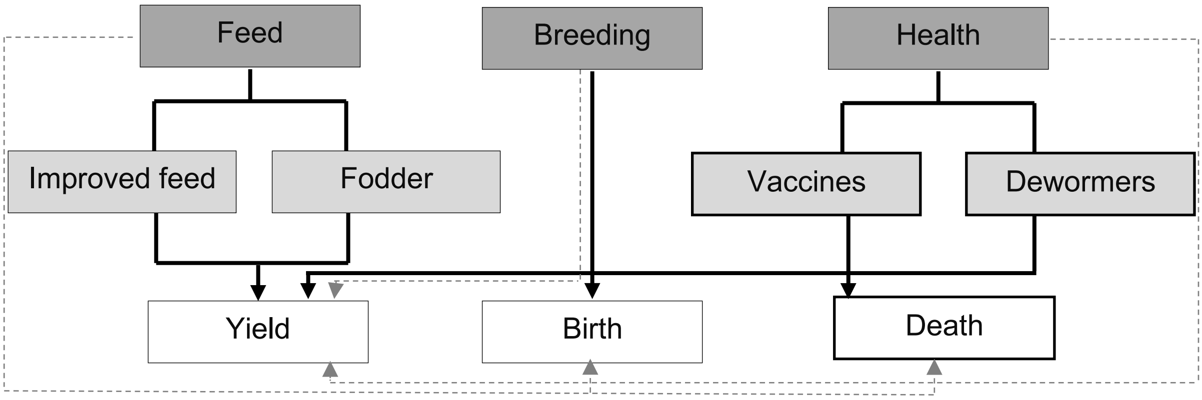
4 METHOD OF ANALYSIS

4.1 A theoretical framework of the effect of livestock interventions

Analyses of the constraints to livestock sector development (FAO 2023, Manzi et al. 2022, Mazimpaka et al. 2017) and sector development plans (Shapiro et al 2017) often emphasize feed availability, breeding services, and health as key strategic interventions to unlock the potential of the livestock sector in developing economies. These interventions impact the livestock system through a variety of complex pathways. However, the theoretical framework in Figure 2 simplifies these pathways, focusing on the primary direct channels (i.e., the solid lines in the figure). For example, improved feed supply or fodder production boosts meat and milk yields. Indirectly, adequate feed can enhance fertility rates and reproductive performance in the herd (see the dotted lines). However, if the feed supply cannot keep up with the herd growth, it may lead to feed insecurity, declining productivity, and increased animal mortality. While these indirect effects are not emphasized in the theoretical framework, they are more thoroughly addressed in the modeling through the systems interdependencies and feedback loops.

Improved reproductive practices, such as artificial insemination (AI), directly enhance conception rates, leading to increased birth rate and better breed mix. In some cases, farmers can select the gender of their calves, further improving the herd's genetic quality and accelerating genetic progress (Washaya et al. 2019, Baruselli et al. 2018, Manzi et al. 2022). This results in a gradual rise in both average meat (or live weight) and milk yields. However, assisted breeding can also create indirect effects, particularly if complementary interventions—such as improved feed supply or a shift from extensive to intensive farming—are not in place. The rapid herd expansion may strain feed availability per animal, leading to suboptimal yields and increase in mortality.

Figure 2: A theoretical framework of the effect of livestock interventions



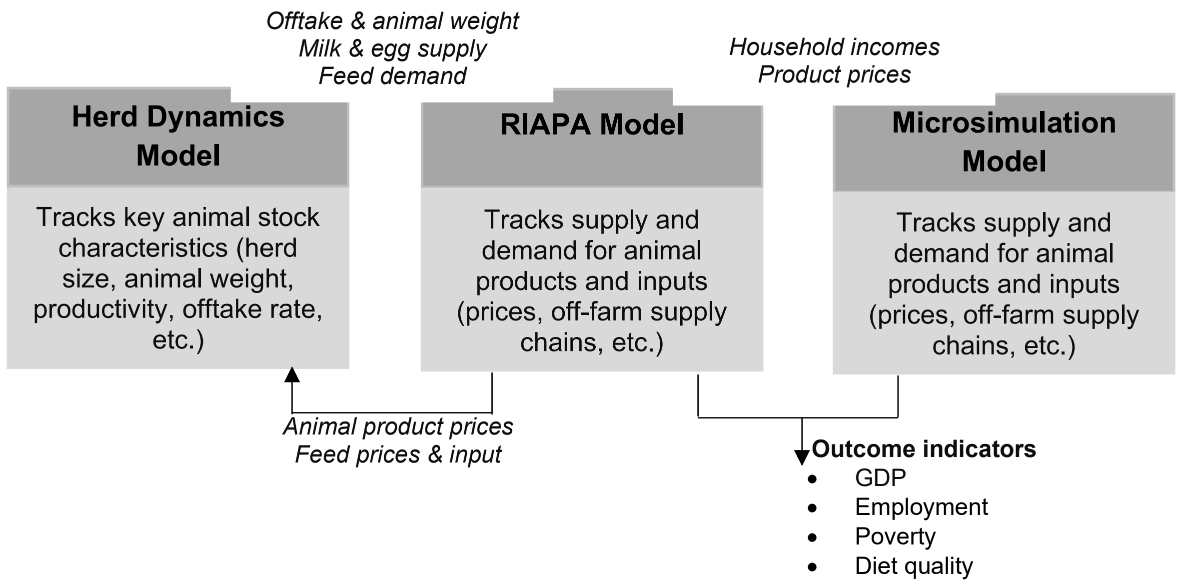
Source: Authors' compilation

Similarly, animal health interventions that increase access to vaccines and dewormers can have varied impacts on herd performance. Vaccines primarily address diseases like foot-and-mouth and lumpy skin, significantly reducing animal deaths. This not only improves yields but also prevents economic losses due to mortality. Dewormers, on the other hand, help control parasites that harm health and productivity, leading to better weight gain and increased milk production. Additional benefits of dewormers include enhanced reproductive performance and reduced mortality, contributing to overall herd resilience.

4.2 Linked Economic and Animal systems (LEAS) model for Rwanda

In this study, we use the Linked Economic and Animal Systems (LEAS) model (Aragie et al., 2021). The LEAS model (Figure 3) is a systems-based analytical approach where components are linked through several handshake variables (price and quantities) depicting information flows both ways. The LEAS model was developed in response to major implications that emerge from the recent literature on livestock systems in developing countries, including the need for systems approach that accounts for (i) the downstream linkages connecting producers and consumers, (ii) the reliance of the livestock sector development on the future trajectory of the broader economy through sectoral interlinkages, and (iii) the need for a holistic approach that helps prioritize livestock sector interventions. This model has been used to assess the response of cattle herds to weather shocks (Aragie and Thurlow 2022), crop and livestock interactions under climate risk (Aragie and Thurlow, 2024), and the implications of national development trajectories on the livestock sector performance (Aragie and Thurlow 2024).

Figure 3: The LEAS modeling framework



Source: Authors' compilation

The LEAS model incorporates a herd dynamics module (HDM) developed in the spirit of Lesnoff (2009-2013) but provides a well-disaggregated presentation of age cohorts and agroecology. The HDM is a lifecycle (stock-flow) module that tracks annual herd size disaggregated by age, sex, breed, and agroecology zone. It also captures stock-flow relationships that depict deeper economic logic too. Economic flows represent the value of the living stocks, offtakes (sales of live animals out of the system), livestock products (e.g., milk or dung), and (ideally) other economic services from livestock (for example, oxen draft power or transport services by pack animals). Given information on consumer demand for animal products and the profitability of animal offtake activities, the HDM estimates new offtake level, remaining herd size, and annual feed requirement.

A few policy interventions are also embedded within the HDM, such as public provision of medicines to improve animal health or access to improved feed to increase on-farm livestock productivity. Environmental variables, such as forage supply and biophysical carrying capacity, are salient features of the model incorporated to capture the impact of climate on herd stock level and productivity. The HDM also incorporates parameters and variables for analyzing shocks (drought, animal disease, etc.) to the livestock system (e.g., Aragie and Thurlow 2024, Aragie and Thurlow 2022).

The HDM is calibrated to cattle, sheep and goat historical data from FAO (2024) while making sure that the base year stock sizes for various animal types are consistent with those reported in the 2020 Agricultural Household Survey data (NISR 2021). In line with Rwanda's LMP (Shapiro et al. 2017), the HDM identifies four livestock systems, and hence build livestock databases separately for each of them: (i) LRLA, (ii) MRMA, (iii) HRHA, and (iv) SP systems. Whereas the FAO provides aggregate national level stock data and NISR (2021) follows administrative level reporting, the LMP was useful in proportionately disaggregating the stock data into those four livestock systems.

We also account for differences in demographic and productivity performance across these systems using initial parameters obtained from Shapiro et al. (2017) as input in the cross-entropy estimation technique introduced earlier in footnote 1. Table 2 shows the age distribution and other selected demographic and productivity parameters for female cattle in LRLA system, which is one of the biggest cattle systems in Rwanda (Figure 1). The cross-entropy technique generates realistic age distribution, age-specific death rates, offtake rates, parturition rates, milk and meat yield per animal that is consistent with meat and milk production quantities in the livestock system, which is assumed proportional to the system's share from the national total. For example, the estimated parturition rates are closer to the 67-78 percent range estimated by Manzi et al. (2018) for various breeds in Rwanda, while the milk yield per day is closer to the 2.8 liter per day estimate in Manzi et al. (2022). Further, the live weight in kg is consistent with the 230kg and 330kg considered for sub-adult and adult cattle in the Rwanda LMP, respectively (Shapiro et al. 2017).

Table 2: Selected demographic and productivity parameters for female cattle for LRLA

Age	Share (%)	Death rate	Offtake rate	Parturition rate	Milking day/lactation	Milk offtake/day	Live weight in kg
<1	19.2	0.12	0.00				35.0
1	15.9	0.11	0.02				144.5
2	13.1	0.08	0.05				261.0
3	10.8	0.03	0.05	0.72	195.7	1.9	261.0
4	9.3	0.01	0.05	0.87	196.3	1.9	348.0
5	8.3	0.01	0.05	0.90	195.8	2.0	348.0
6	7.4	0.01	0.07	0.94	195.4	2.2	348.0
7	6.4	0.01	0.16	0.87	193.2	2.2	348.0
8	5.0	0.03	0.30	0.72	189.2	2.3	348.0
9	3.2	0.05	0.49	0.63	185.4	2.4	348.0
10	1.4	0.07	0.82	0.49	181.9	2.4	348.0
11	0.1	0.21	0.78				332.3

Source: Authors' compilation using cross-entropy technique

One novel feature of the integrated model is the systematic link between the HDM and the economic model. Using information on consumer demand for animal products and the relative profitability of animal offtake activities from the economywide model, the HDM estimates offtake requirements, remaining herd sizes, and annual feed requirements. The dynamics in the livestock model are linked back to the economywide model through the annual growth rate in the animal production subsectors' (cattle and milk production) capital. As the economic model solves for successive years (from t_0, which is the base year to t_5, which is the final year of the simulation in the current model), the accumulated livestock capital in the cattle sector updates every year by the rate of growth in meat offtake calculated in the HDM. Similarly, livestock capital in the milk production sector in the economic model updates in response to the growth in milk offtake from the HDM.

At the core of LEAS integrated model is a recursive dynamic Computable General Equilibrium (CGE) model known as IFPRI's Rural Investment and Policy Analysis (RIAPA) model. RIAPA is based on Diao and Thurlow (2012) and has been used to analyze agricultural policies and investments (Pauw and Thurlow 2015, Benfica et al. 2019) and other socioeconomic policies (Burns et al. 2013, Aragie et al. 2024). RIAPA consists of both behavioral equations that describe economic decisions related to production, marketing, consumption, etc., of economic agents–firms, households, and other institutions–and structural equations that specify accounting relationships between the incomes and expenditures of individual agents and within the macroeconomy. In this model, production is defined by a multi-level nested structure, specified for each sector, with fixed input-output relationships and variable factor use governed by a constant elasticity of substitution (CES) technology function.

Household consumption consists of either marketed commodities or home-produced goods. Demand for commodities by representative households is determined by a linear expenditure system (LES), whereby minimum quantities of each commodity are considered "subsistence" consumption and are unresponsive to price changes; the balance of consumption expenditure is "discretionary" and responds to relative price or income changes. In the model, market prices adjust to clear the overall national supply and demand for each product.

The government collects direct and indirect tax revenue, provides government services, and makes welfare transfers to households. Surplus funds in the recurrent budget are available for public investment financing, while a deficit is financed through government borrowings. Households and incorporated business institutions serve as other sources of national savings, given their fixed marginal propensities to save. Total savings in the economy are pooled together to determine total investment.

In this recursive dynamic model, selected parameters are updated between periods based on long-term trends and future outlooks to reflect changes in factor supply and productivity, population growth, government spending, and foreign capital inflows. The model is calibrated for a five-year period. Capital stocks within each sector and region are updated each year to reflect depreciation and investments from the previous period. The capital updating process opens a way to link the HDM and the economic model as discussed earlier.

The RIAPA model applied in this study is calibrated to a 2021 Social Accounting Matrix (SAM) for Rwanda (IFPRI et al. 2022) with a detailed account structure, including 80 commodities (31 in agriculture), 13 factors of production (labor, land, and capital), and 15 representative farm and non-farm (rural and urban) households categorized by expenditure quintile. Eight of the sectors in this Rwanda model are livestock-related primary and processing sectors.

4.3 Measuring the impact of alternative livestock interventions and spending options

In addition to the demographic and productivity parameters reported in Table 2, the HDM incorporates various policy and shock parameters to assess their impacts on the livestock system. This study explores the effects of alternative livestock sector interventions—namely, feed availability, breeding and genetic services, and health—under potentially probable scenarios of biased and balanced spending. Rwanda's current LMP (Shapiro et al. 2017) places significant emphasis on breeding interventions. However, it is worth investigating whether feed or health-oriented interventions might be more cost-effective, or if policymakers should consider implementing a feed or health-biased approach in a different context.

The number of additional animals reached by each intervention under various spending options must be calculated to determine their associated impacts endogenously in the system. The direct effect of an expenditure can be measured based on the scale of the investment outcome, the system's impact pathways (e.g., death rate, yield, etc.), and the associated impact coefficient. The investment outcome can be defined as the additional coverage achieved through public spending in a particular intervention, such as breeding services. For instance, the investment outcome—measured as the number of cows inseminated per year—depends on the level of public spending and the unit cost ($) per service or per animal (as shown in Table 3). FAO (2023) estimates the cost of improved feed in Rwanda at $0.27/kg (365 RWF), while USAID (2013) estimates the cost of a successful cattle breeding service in Ethiopia at $11.4 per service. These estimates provide a benchmark for understanding the cost implications of each intervention and the additional coverage that can be achieved.

Elasticities, or impact coefficients, quantify the direct productivity gains from investments and are specific to each intervention. Each intervention has distinct impact pathways, depending on the demographic or productivity parameter it initially affects. For example, Washaya et al. (2019) and Baruselli et al. (2018) report that assisted breeding through artificial insemination (AI) improves the likelihood of conception by over 50 percent, compared to natural mating. This increase in conception rates is expected to shift the breed mix, leading to enhanced milk and meat yields. Studies by Manzi et al. (2022) and Tsegaye et al. (2023) highlight that milk yield among crossbred or exotic breeds can be over three times higher than that of indigenous breeds, further emphasizing the potential productivity gains from breeding interventions.

Table 3: Selected HDM intervention parameters

	Cattle	Sheep	Goat	Source
Scalers				
TLU conversion factor	1.0	0.1	0.1	Ahmed and Mesfin (2017)
Current carrying capacity	0.8	0.6	0.6	Expert opinion
Elasticities				
The effect of breeding service on fertility	1.5	1.5	1.5	Washaya et al. (2019); Baruselli et al. (2018)
The effect of improved breeds on milk yield	3.6	-	3.6	Manzi et al. (2022); Tsegaye et al. (2023)
The effect of improved breeds on meat yield	1.3	1.3	1.3	Tsegaye et al. (2023)
Price elasticity of offtake rate	0.4	0.4	0.4	Expert opinion
Death rate elasticity of carrying capacity	1.2	1.3	1.3	Expert opinion
Meat elasticity of feed supply	1.5	1.2	1.2	Expert opinion
Milk elasticity of feed supply	2.5	1.5	1.5	Expert opinion
Unit cost ($)				
Cost of improved feed (/kg)	0.3	0.3	0.3	FAO (2023)
Cost of fodder (/kg)	0.1	0.1	0.1	Assumption
Breeding cost (/head/year)	11.4	11.4	11.4	USAID (2013)
Vaccine cost (/head/year)	3.8	3.8	3.8	USAID (2013)
Dewormers cost (/head/year)	3.8	3.8	3.8	Assumption

Source: Authors' compilation

5 SCENARIO DESIGN

In this study, we design three major sets of scenarios: (i) baseline scenario, (ii) balanced spending scenario, and (iii) biased spending scenarios.

5.1 Baseline Scenario

To establish a benchmark against which the intervention scenarios are assessed, we first formulate a baseline scenario that reflects the typical performance of Rwanda's crop and livestock sectors as well as the overall economy in the absence of the interventions. In the baseline scenario, we assume the long-term growth trend in Rwanda is maintained, where the crop and livestock sectors grow by 8.0 and 7.0 percent, respectively, resulting in an overall GDP growth of just under 4.0 percent. This long-term growth assumption helps to idealize against the recent erratic agricultural sector performance in Rwanda partly due to ongoing global shocks.[2] The model estimates the economic and livestock systems over a period of five years (t_1-t_5) from a base year at t_0, which corresponds to the upcoming Fifth Strategic Plan for Agriculture Transformation (PSTA5) period and also sufficient enough to capture the dynamics of the economic and livestock systems after the intervention and spending scenarios considered below.

5.2 Balanced Spending scenario

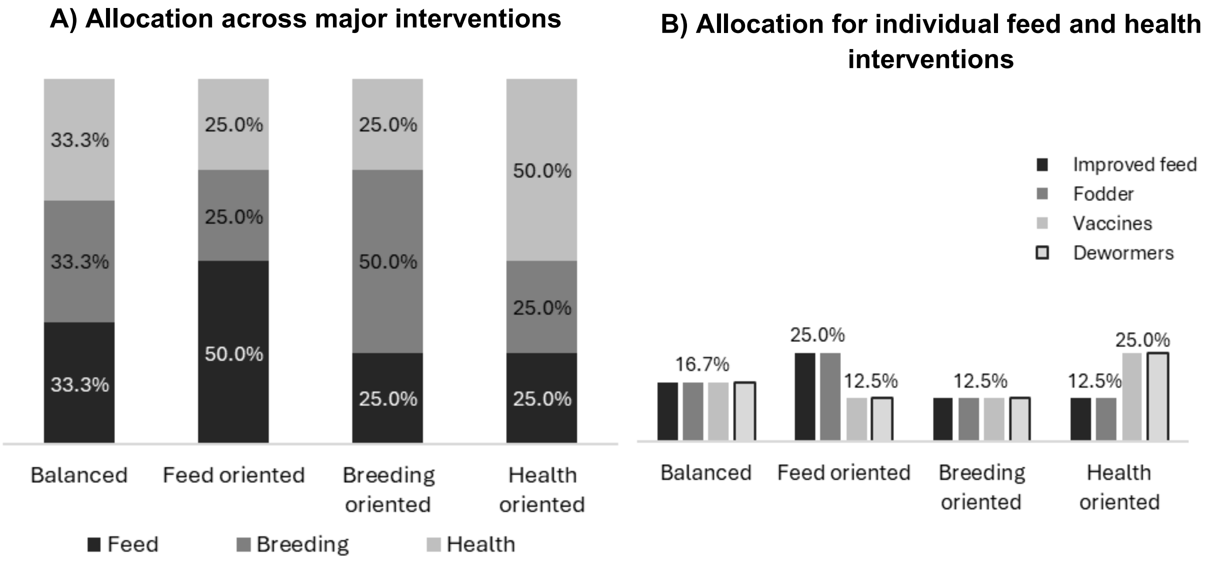
In this scenario, we introduced three major livestock intervention areas, including feed, breeding, and animal health. Animal feed constitutes two separate interventions: spending on improved feed and spending on fodder production. These two feed sources differ by source and effect on livestock performance. Likewise, the animal health intervention incorporates vaccines and deworming, which impact the livestock system differently. Whereas vaccines save animals from preventable deaths due to diseases, dewormers principally enhance feed conversion, livestock health and productivity. In the simulations, these three major interventions are considered separately and in combination.

For simulation design purposes, we assume one-third (or about $14.5 million) of average annual red meat and dairy value chain development budget indicated in Rwanda's LMP (Shapiro et al 2017) is spent equally in this balanced scenario on the three broad intervention areas, each sharing 33.3 percent (Figure 4).[3] This is also closer to 30 percent of the annual proposed direct spending on livestock during the upcoming PSTA-5 period. Each component of the feed and health interventions share the budget allocated to the sub-component equally. We consider five years spending period from the initial year t_1 to t_5, where t_0 refers to the base year before the interventions are implemented.

[2] After an encouraging growth performance of over 5 percent over 2014-2019, agriculture growth in Rwanda stagnated at below 2 percent since 2022 (NISR 2024).

[3] The LMP (Shapiro et al., 2017) proposes a $157.3 and $60.8 million (total = 218 million) investment cost to carry out the Rwanda LMP roadmap over five years. Also, during the program design process, PSTA-5 considers a $260 million spending over 5 years on animal health, breeding and feed.

Figure 4: Budget allocation across investment rates and spending scenarios



Feed: This intervention, absorbing 33.3 percent of the total budget under the balanced scenario, constitutes improved feed supply and fodder production interventions.

Improved feed: Adequate and quality feed access has been a fundamental bottleneck constraining the livestock sector in most countries in Africa. Policy documents, including the LMP (Shapiro et al. 2017) and PSTA-4 (MINAGRI 2018) in Rwanda have long highlighted the centrality of the feed system to unlock the sector's potential. Improved feed is typically more nutrient-dense and higher in quality, providing better energy, protein, vitamins, and minerals. This leads to faster growth, better weight gain, and higher milk production. This sub-scenario considers the production and productivity impacts of improved feed investments. Throughout the spending scenarios, improved feed production takes half of the budget allocated to feed overall.

Fodder: Currently, approximately 0.4 million hectares of land in Rwanda are designated for fodder production (the country has committed to an almost zero grazing feeding practice), while 1.9 million hectares are used for crop production (FAO 2024). Under this scenario, we assume that both productivity growth and land expansion contribute to the envisaged fodder production growth, with no substitution effect on cropland. Again, it is assumed that about half of the funds allocated to feed are committed to fodder production.

Breeding: About 35 percent of cattle in Rwanda are identified as less productive local breeds (NISR 2021). Research generally indicates that increasing access to breeding services, such as artificial insemination (AI), would increase fertility rates and also help alter the breed mix to a much more productive herd. This scenario assesses the potential contribution of increased access to breeding services in revitalizing the performance of the livestock sector and the wider economy. This intervention is expected to lead to the same level of production from either a smaller herd or a higher level of output from the same size herd.

Health: This intervention constitutes vaccines and deworming.

Vaccines: About 40 percent of cattle, 25 percent of goats and up to 30 percent of sheep suffer from diseases (NISR 2021), with considerable consequences on animal numbers, meat and milk production levels, and farmers' welfare. Access to affordable animal vaccines would help reduce animal deaths and losses in economic assets associated with the dying herd. This sub-scenario evaluates the potential impact of increased access to animal vaccines on various dimensions of the economy and the livestock system. Vaccines are half of the funds allocated to animal health.

Dewormers: Parasitic infection remains a critical constraint to the development of the livestock system in tropical areas (Bishop 2012, Zvinorova et al. 2016). Such infections reduce livestock productivity by significantly affecting animal health, digestion, and nutrient absorption. This intervention, which constitutes the other half of the health sector spending, primarily targets a reduction in parasitic infections which leads to rapid improvements in animal health and corresponding positive impacts on both meat and milk yields.

Combined scenario: In this scenario, all three interventions – feed, breeding, and health – are implemented jointly, acknowledging the possible complex impact interrelationships between the interventions. For instance, both breeding and vaccines may rapidly increase the herd size, and exert pressure on per capita feed availability, whereas the feed intervention may help maintain productivity by availing the required feed for the expanding stock. This combined scenario maintains the equally weighted spending pattern (Figure 4) and will be used later as a benchmark to assess the impact of the biased spending options.

5.3 Biased spending scenarios

The individual scenarios in section 4.1 help to depict the causal mechanisms through which each intervention impacts economic and livestock system indicators. However, they do not provide a clear strategy for policymakers regarding budget allocation. To address this, biased spending scenarios explore three broader spending options, offering guidance for policy dialogue: (i) feed-oriented spending, (ii) breeding-oriented spending, and (iii) health-oriented spending.

In the feed-oriented spending option, half of the total budget is allocated to feed-related interventions, while breeding and health interventions each receive 25 percent of the budget (Figure 4, Panel A). Similarly, in the breeding-oriented and health-oriented scenarios, breeding and health interventions are allocated 50 percent of the budget, respectively, with the remaining budget split equally between the other two. The breeding-oriented spending scenario closely aligns with Rwanda's current LMP for red meat and dairy value chain development, which proposes allocating nearly 50 percent of the budget to breeding interventions (Shapiro et al. 2017). As with section 4.1, each sub-component of feed (improved feed and fodder) and health (vaccines and dewormers) receives an equal share of the budget allocated to the broader intervention areas (Figure 4, Panel B). The outcomes of these biased spending scenarios are then compared to the balanced spending scenario discussed earlier, providing a more comprehensive view of intervention and spending options.

6 MODEL RESULTS AND DISCUSSION

6.1 Economic and livestock system impacts under a balanced spending pattern.

Impact on the economy

The livestock sector in Rwanda contributes 14.6 and 36.0 percent to both total GDP and agricultural GDP, respectively. Table 4 outlines the initial and cumulative effects of the feed, breeding, and health interventions on different segments of the economy when the budget is allocated equally. Our discussion focuses on the agriculture sector broadly and then details the primary livestock production and its components (cattle, milk, and small ruminants), as well as processed production (meat and dairy) to which the intervention areas have closer and stronger effects. When appropriate, we also split the reporting period into 'immediate' to refer to the impact at the start (t_1) of the spending period, and 'cumulative' to refer to the average impact throughout the spending period (t_1-t_5) relative to the baseline scenario.

The interventions analyzed have a moderate impact on agricultural GDP, with an immediate (i.e., in t_1) combined effect of 0.8 percent and a cumulative effect of 1.0 percent by the fifth year. Breeding has the largest individual impact on agriculture GDP, both immediately (0.4 percent) and cumulatively (0.6 percent), highlighting its critical role in boosting overall agricultural performance. In the livestock sector, the immediate combined effect is substantial at 6.5 percent, with breeding contributing greatly to this effect with a growth of 3.0 percent, followed by health (2.6 percent) and feed (1.5 percent).[4] The livestock sector experiences a cumulative combined effect of 8.6 percent, reflecting sustained improvement over time, particularly driven by breeding interventions.

The immediate and cumulative effects of the interventions on livestock vary across its sub-components. Breeding consistently has the highest impact on milk and dairy, with strong cumulative effects that underscore the long-term benefits of genetic improvement and reproductive efficiency. Health interventions, on the other hand, have significant immediate effects, especially on cattle and meat, highlighting their crucial role in improving productivity, stock size, and output volume. Feed interventions generally have a smaller impact compared to health and breeding. Overall, the cumulative effects are larger than the initial effects, indicating that these interventions lead to sustained improvements over time.

Table 4: Changes in GDP under alternative intervention/spending areas (%)

	Immediate Effect				Cumulative Effect			
	Feed	Breeding	Health	Combined	Feed	Breeding	Health	Combined
Primary production								
Agriculture	0.2	0.4	0.3	0.8	0.2	0.6	0.3	1.0
Livestock	1.5	3.0	2.6	6.5	1.4	5.0	2.6	8.6
Cattle	0.7	0.5	2.8	3.2	0.9	1.2	3.5	5.3
Milk	3.0	7.3	3.7	13.5	2.4	11.7	3.2	17.0
Small ruminants	0.6	-0.1	2.7	2.9	1.0	-0.1	2.7	3.2
Processed production								
Meat	0.8	0.6	3.3	3.8	1.1	1.4	4.1	6.2
Dairy	1.8	4.5	2.2	8.0	1.6	8.3	2.1	11.6

Source: Authors' calculations

Annex Table 1 presents the initial and cumulative effects of various feed and health interventions—improved feed, fodder, vaccines, and dewormers—on both primary production (livestock, cattle, milk, and small livestock) and processed production (meat and dairy). It highlights the significance of improved feed for achieving stronger positive effects on cattle, small livestock, and dairy, with more substantial initial and cumulative impacts compared to fodder in most categories. Further, dewormers consistently yield positive cumulative effects, especially in meat, milk, and small ruminants (sheep and goat), consistently outpacing the effects of vaccines.

Impact on the livestock system

In this section, we report impacts on meat and milk yield and output, as well as changes in stock and death rate associated with the intervention. The change in meat yield is measured by comparing the average live weight of animals before and after an intervention. We observe that equal investment in feed, breeding, and health interventions under the combined scenario leads to an increase in average meat yield, with yield effects growing over time and reaching 12.5 percent by the end of the simulation period compared to outcomes without these investments (Figure 5, Panel A).

Each of the three spending components considered in the combined scenario contributes differently to the overall impact discussed above. Spending on feed and health interventions leads to increases in meat and milk yields, with animal health measures demonstrating considerably stronger immediate and sustained effects. The impact of feed on meat yield gradually declines, as faster stock growth—resulting from a decrease in deaths due to improved carrying capacity and lower offtake rates—forces per capita feed availability to stagnate or slightly decline. On the other hand, breeding interventions result in an immediate and noticeable reduction in meat yield—by up to 3.9 percent—due to the accelerated multiplication of the herd facilitated by assisted breeding, which increases fertility and presents challenges to feed availability. Over time, the integration of more productive breeds into the herd contributes to a gradual recovery in meat yield per animal.

Panel A also presents the change in milk yield associated with equal spending across feed, breeding, and health interventions. Combining these three broad interventions with an equally weighted level of spending shows no noticeable effects on milk yield in the first two years due to the opposing yield effects of breeding and health interventions. The initial negative average effect on milk yield during this period mirrors the situation observed in meat yield: faster herd expansion limits per capita feed availability, negatively impacting milk yield. Conversely, health interventions—primarily dewormers—contribute positively to yield. In later periods, milk yield accelerates under the combined scenario, reaching up to 27 percent more than in the no-intervention or baseline scenario. Notably, approximately two-thirds of this increase in milk yield is attributed to spending on breeding interventions. Additionally, investment in animal health remains crucial for improving milk yield.

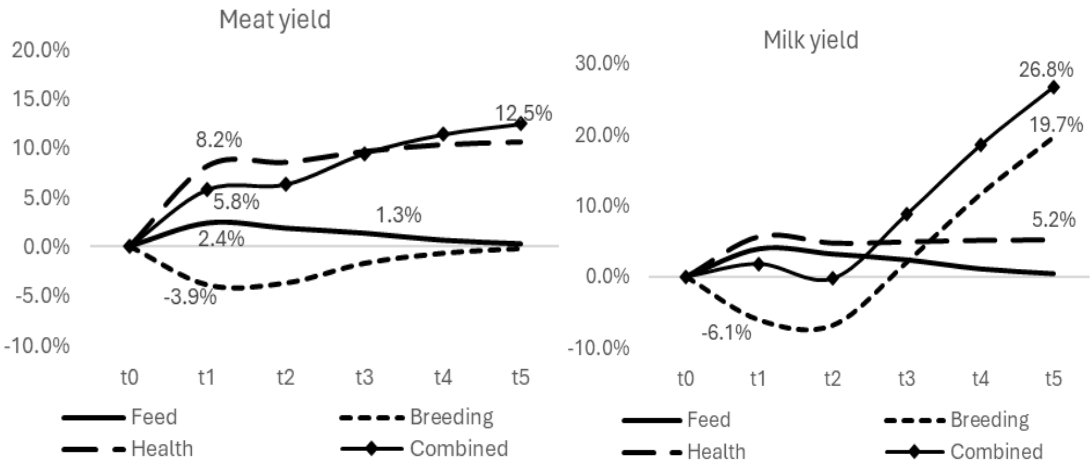
In the simulation design, the feed and animal health interventions comprise two distinct components. The feed intervention includes improved feed and fodder production, while the health intervention encompasses vaccines and dewormers. As detailed in the scenario design section, the budget allocated to each of the feed and health sub-groups is further divided equally among these components. Therefore, apart from the general equilibrium effect, the impact of each component (e.g., vaccines and dewormers) contributes to the overall effect of the health component.

Figure 5, Panel B, illustrates the contrasting contributions of these components to the overall feed and health impacts discussed earlier. Spending on improved feed has a more significant effect on meat and milk yields due to its quality and relative weight in the quality-adjusted total feed supply, which enhances effective feed availability in the system more quickly than spending on fodder, which has a lower quality scaling factor.

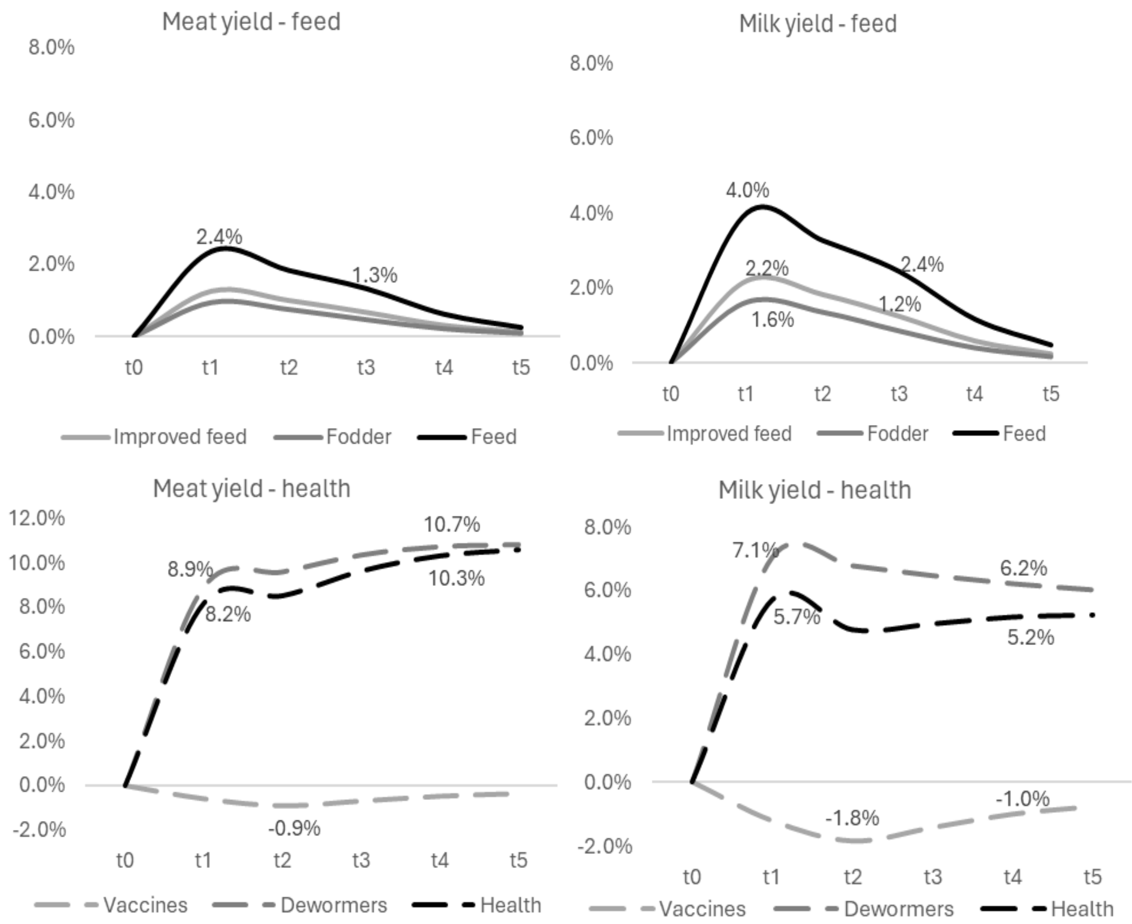
The comparison of the effects of vaccines and dewormers on meat and milk yield is particularly noteworthy. The overall growth impact of the animal health intervention reported in Panel A is primarily driven by spending on dewormers, which enhance average meat and milk yields. In contrast, without complementary investments, such as those in feed, increased adoption of animal vaccines slightly dampens both meat and milk yield due to potential stress on per capita feed supply as mortality rates decline. This yield reduction effect is especially pronounced for milk yield. This finding aligns with other studies (Summer et al. 2019, Leister et al. 2015) that indicate a greater responsiveness of milk productivity to feed supply compared to meat.

Figure 5: Changes in meat and milk yield under alternative intervention areas

A) The impacts of feed, breeding, and health interventions



B) The contribution of different feed and health interventions



Note: Meat yield is arrived at by using average live weight of cattle, sheep, and goat and applying TLUs to obtain system average. Average milk yield is arrived at by using average milk yield per year from cattle and goats and applying TLUs to obtain system average.

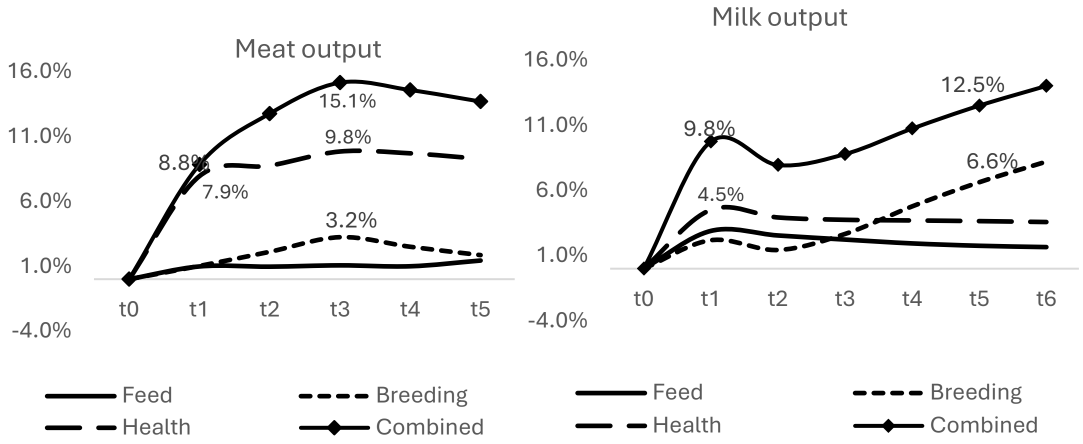
Figure 6 reports changes in meat and milk output under the alternative intervention areas. Panel A compares impacts from feed, breeding, and health interventions separately, and in combination. Panel A reports how individual components of feed (improved feed and fodder) and health (vaccines and deworming) contribute to the net effect from feed and animal health reported in Panel A.

Panel A in Figure 6 illustrates that balanced spending on animal feed, breeding, and health interventions leads to a substantial and sustained increase in both meat and milk production. However, the contributions of each intervention vary in terms of magnitude and timing. Animal health interventions emerge as the dominant factor driving meat production, accounting for approximately two-thirds of the total increase throughout the simulation period. Meanwhile, breeding interventions become the primary driver of milk production growth in the second half of the period. This strong effect of breeding on milk output, coupled with a noticeable rise in meat production starting from the third year (t_3), reflects a gradual shift in the herd composition toward more productive breeds due to the breeding intervention. The figure also indicates a slightly stronger immediate impact on milk production (9.8 percent) compared to meat production (8.8 percent). This is largely attributed to assisted breeding, which boosts fertility and increases the number of lactating animals. However, the rapid herd expansion brought about by the intervention also leads to a temporary decline in per capita feed availability, negatively affecting productivity. Consistent with the results in Figure 5 on meat and milk yields, the impact of feed interventions on output is moderate, though slightly stronger for milk production due to a more responsive milk yield.

In line with Panel B in Figure 5, Panel B in Figure 6 suggests that improved feed investment is effective in accelerating meat and milk output in contrast to fodder. Improved access to dewormers also contributes greatly to the increase in meat and milk output resulting from the health sector intervention. In contrast to the slowdown in meat and milk output due to improved access to vaccines which primarily intended to reduce animal deaths from diseases, this intervention results in an increase in meat offtake due to a general increase in the stock.

Figure 6: Changes in meat and milk output under alternative intervention areas

A) The impacts of feed, breeding, and health interventions



B) The contribution of different feed and health interventions

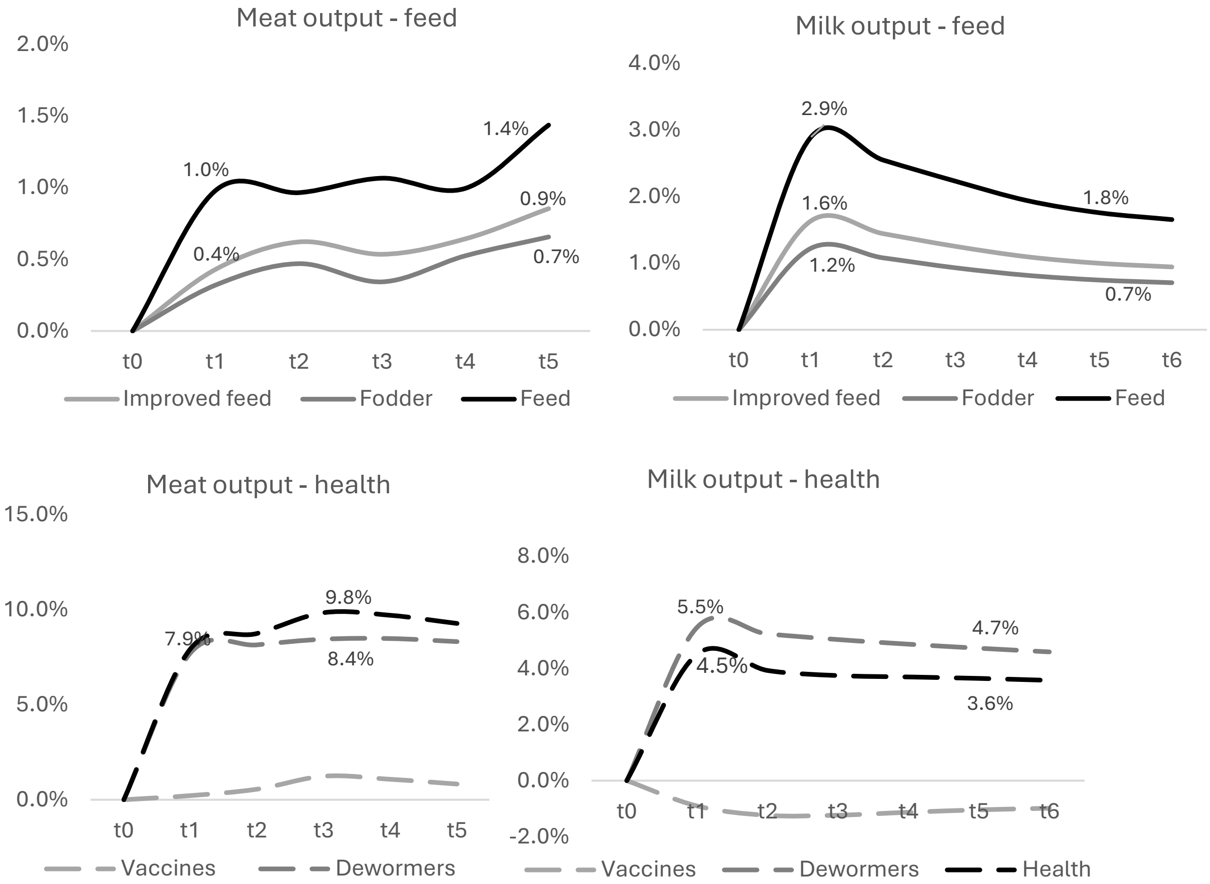


Figure 7 reports the impact of livestock sector interventions on stock size and animal mortality. Balanced investment across the three major interventions—represented in the equally-weighted combined scenario—results in a 2.4 percentage point faster growth in livestock numbers in Rwanda compared to growth without these investments (Panel A). Improved access to feed plays a key role in this stock growth through two main mechanisms: (i) increased feed availability reduces pressure on the system, leading to lower offtake by farmers, and (ii) better feed access mitigates feed shortage-induced deaths. However, investments in breeding and health interventions alone do not necessarily accelerate herd growth, as the feed constraint becomes a limiting factor in the absence of feed interventions.

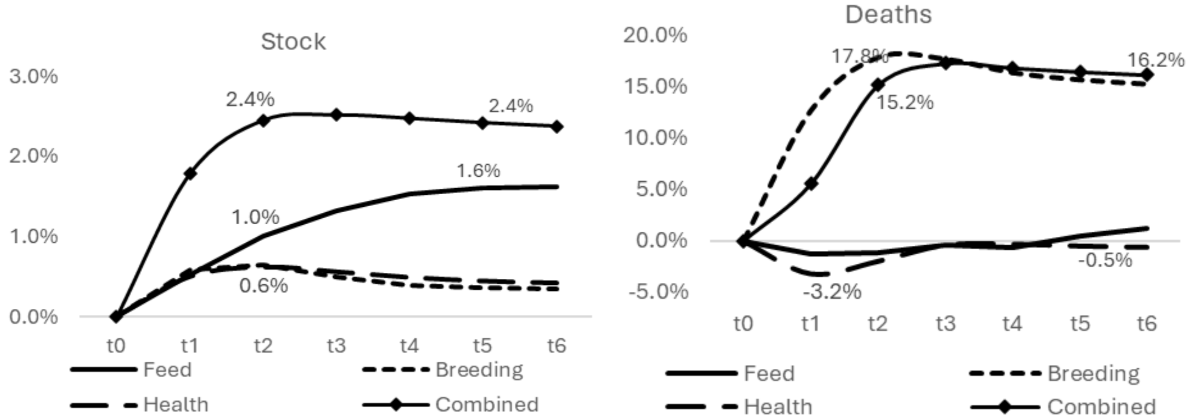
The feed constraint, triggered by herd expansion due to the breeding intervention, is evident in the faster rise in animal deaths. Notably, investment in animal health significantly reduces deaths by up to 3.2 percent. However, this reduction is not sufficient to offset the increase in deaths resulting from stock growth driven by breeding, which intensifies pressure on feed availability.

The lower panel of Figure 7 shows the contribution of individual feed and health interventions on stock size and animal deaths. Consistently, investment in improved feed has a greater impact on herd size than fodder production, primarily due to its stronger effect on the total feed supply for the same level of investment. While improved feed leads to herd expansion, it also results in a higher number of deaths as the overall population base increases.

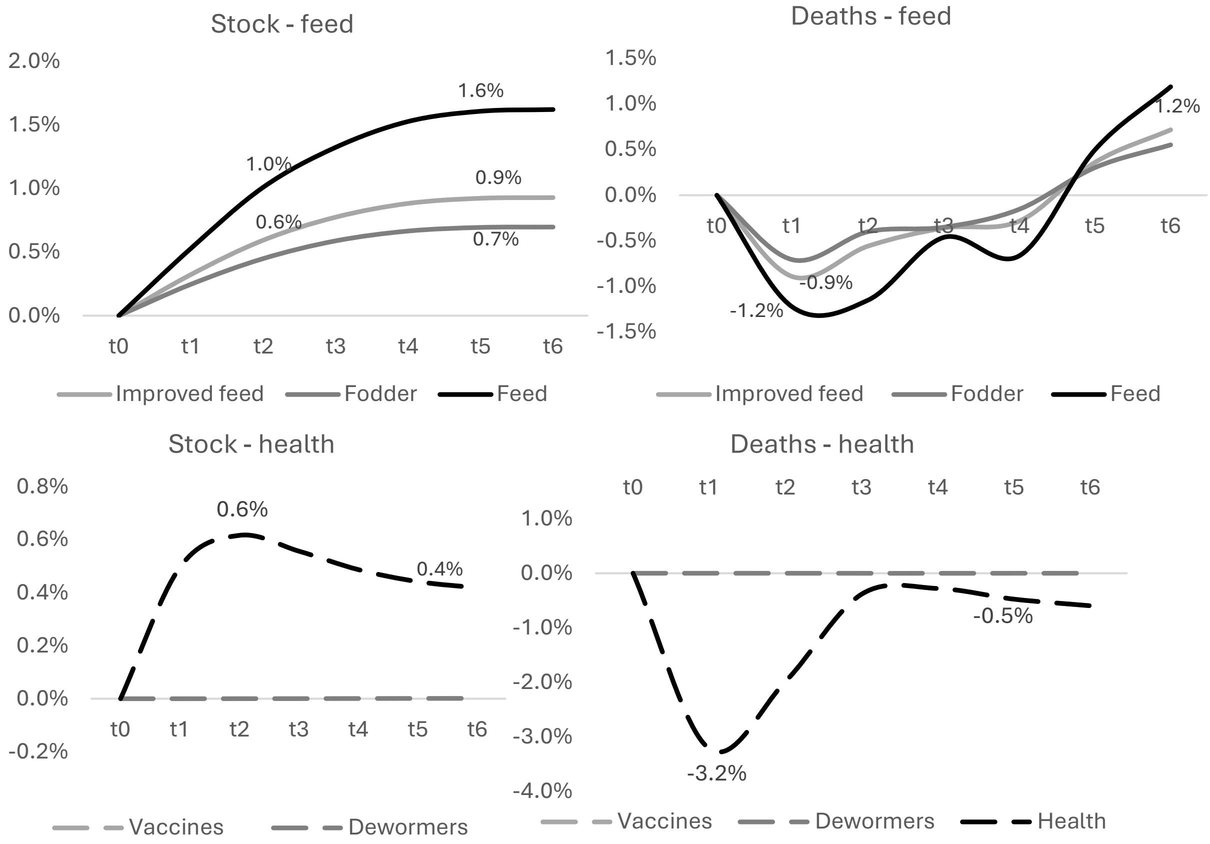
The individual animal health interventions have significant implications for stock size and animal deaths. As shown in Panel B, vaccines—closely aligned with the "health" scenario—drive the full impact of health interventions on both stock size and deaths, as reported in Panel A. Dewormers, primarily aimed at increasing animal productivity, have minimal influence on death rates, resulting in a negligible effect on both stock size and the number of deaths.

Figure 7: Changes in animal stock and deaths under alternative intervention areas

A) The impacts of feed, breeding, and health interventions



B) The contribution of different feed and health interventions



6.2 Economic and livestock system impacts under the alternative spending pattern

Impact on the economy

Due to the overall moderate effect of the interventions on agricultural GDP (0.8 percent total effect under the equally weighted combined scenario reported in Table 4), the alternative spending options—feed-oriented, breeding-oriented, and vaccine-oriented— do not alter the overall effect. However, results differ when effects on livestock and its sub-components are considered. During the initial years of the spending period, the breeding-oriented budget generally outweighs all other scenarios including the balanced budget option mainly through its stronger impact on GDP of the milk sector, which grows by 1.9 percent above the balanced scenario. Due to the cheaper supply of raw milk under the breading-oriented spending scenario, the dairy processing sector also outperforms by 1.0 percent. The health-oriented spending scenario generates superior cattle and meat GDP effects, principally because of the reduction in deaths and gains in liveweight.

Overall, the initial and cumulative effects remain consistent in terms of the direction of change as in the balanced spending scenario, although the cumulative effect becomes significantly bigger in magnitude as it takes time for some of the interventions to exert their full impact. For example, breeding takes a couple of years after the initial intervention before finally impacting the average meat and milk yield of the herd.

Table 5: Percentage point deviation in GDP growth from the balanced spending scenario (%)

	Intermediate effect			Cumulative effect		
	Feed oriented	**Breeding oriented**	**Health oriented**	**Feed oriented**	**Breeding oriented**	**Health oriented**
Primary production						
Agriculture	-0.1	0.1	0.0	-0.2	0.2	0.0
Livestock	-0.9	0.6	0.3	-1.5	1.4	0.0
Cattle	-1.0	0.0	1.2	-1.1	-0.3	1.3
Milk	-1.5	1.9	-0.4	-3.0	3.9	-1.3
Small ruminants	-0.3	-0.8	1.2	-0.3	-0.9	1.2
Processed production						
Meat	-1.2	0.0	1.4	-1.3	-0.3	1.5
Dairy	-0.8	1.0	-0.3	-1.9	2.5	-0.9

Source: Authors' calculations

Impact on the livestock system

Figure 8 compares the effects of the three biased spending options on selected livestock indicators such as meat and milk yield, meat and milk output, animal stock, and deaths. These impacts are measured as percentage point deviations from the growth rates observed under the balanced spending scenario. Among the three, only the health-oriented spending option clearly surpasses the balanced scenario, particularly in terms of meat yield (Panel A). This improved performance is primarily driven by the rapid expansion in deworming outreach, which has a more pronounced impact on meat yield (as shown in Figure 5) compared to vaccines. The meat yield gain from the health-oriented spending scenario remains sustainably higher, exceeding the balanced scenario by more than 4.5 percent. In contrast, both the feed- and breeding-oriented spending scenarios exhibit a weakening in meat yield gains. Under the feed-oriented scenario, the deviation from the balanced spending growth trajectory worsens over time, due to stagnation in breed composition and the absence of yield gains that would otherwise be achieved through greater dewormer access. Meanwhile, the deviation under the breeding-oriented spending scenario gradually diminishes, as the productivity impacts of improved breeds in the herd begin to materialize, leading to eventual recovery in meat yield growth.

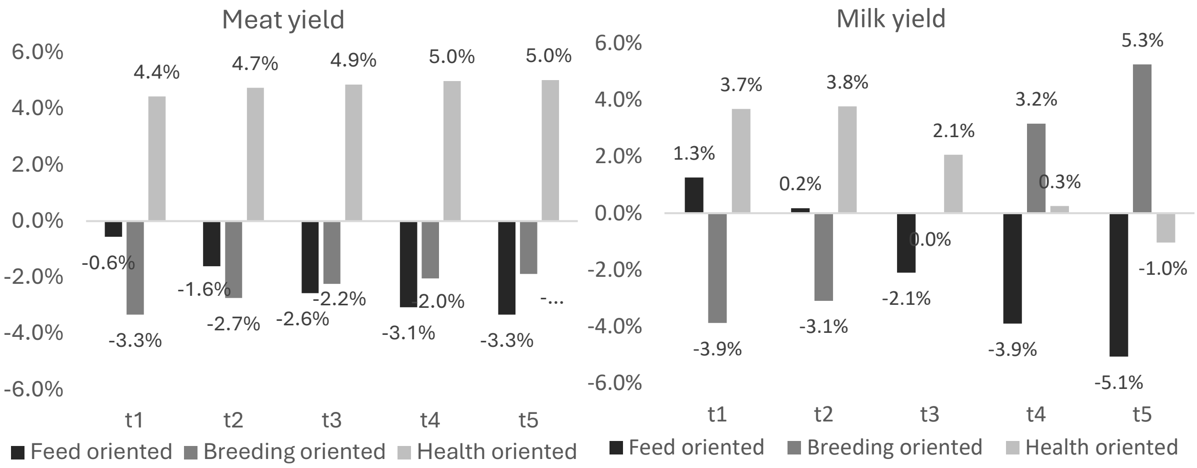
The effect on milk yield demonstrates significant variation over time across the different spending options. In the early periods (t_1–t_3), both the feed- and health-oriented spending scenarios outperform the balanced spending scenario. However, these initial gains fade in the later periods, particularly under the feed-oriented scenario. This decline is primarily due to a rapid increase in stock, resulting from fewer feed-related deaths, without a corresponding improvement in breed quality. As a result, feed supply becomes increasingly strained, negatively impacting milk yield. Conversely, the breeding-oriented spending scenario shows a delayed but stronger impact on average milk yield. While the initial effects are modest, by t_4, the breeding-oriented scenario surpasses the milk yield gains seen under the balanced spending approach. This improvement stems from a gradual enhancement in herd composition, with more productive breeds contributing to a higher milk yield over time.

Panel B illustrates the comparative impact of the spending options on meat and milk output. Health-oriented spending accelerates the growth of meat output, increasing by 3.5 percentage points faster than the balanced spending scenario. Both the feed- and breeding-oriented spending options, however, remain less effective over the simulation period. The decline in meat output under the feed-oriented scenario is attributed to a reduction in slaughter rates, driven by a per capita feed supply increase, which reduces the need to cull animals. In terms of milk output, the health-oriented spending scenario also outperforms the balanced scenario, although the growth in milk output is relatively modest—under 1 percent—compared to the more substantial gains in meat output. The feed- and breeding-oriented scenarios exert similar pattern of change in milk output to their effects on milk yield, but the overall output effects are notably lower. This is largely due to the mediating effect of stock size, where increases in herd numbers dilute the direct productivity improvements, leading to lower overall gains in milk output.

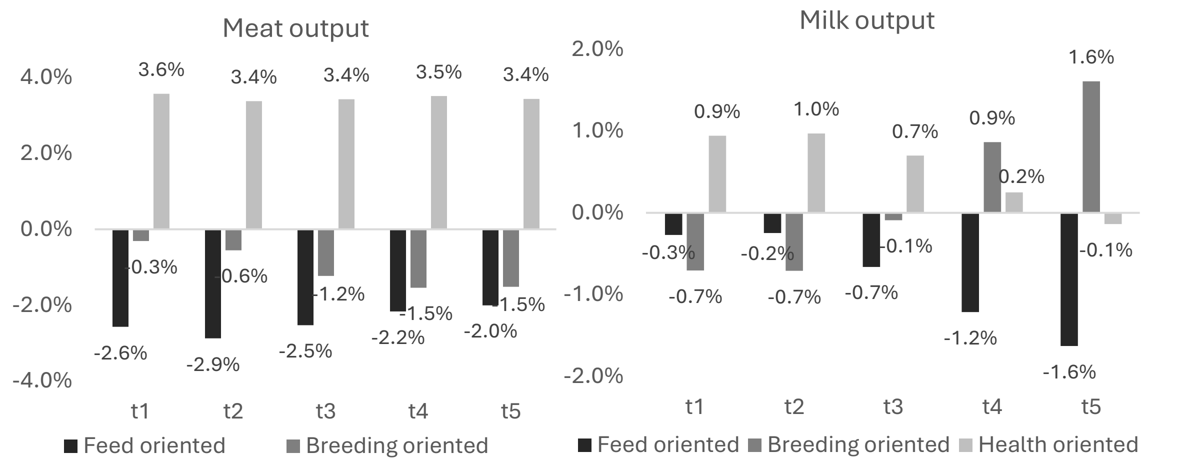
Finally, Panel C highlights the percentage point deviation in animal stock and deaths across the spending options. Interestingly, the feed-oriented spending scenario slightly outperforms all other options, including the balanced scenario, in terms of stock size growth. This is attributed to the increase in per capita feed availability, which supports strong herd growth by mitigating feed shortages. In contrast, the breeding- and health-oriented spending scenarios are unable to fully alleviate the carrying capacity constraints of the system. As a result, these scenarios exhibit slower stock growth. This slower expansion is driven by the system's carrying capacity, which is modeled through adjusted death and offtake rates, reflecting the natural limitations on herd growth. These factors are built into the model to realistically capture the impact of resource availability on livestock population dynamics.

Figure 8: Percentage point deviations in livestock indicators from balanced spending scenario

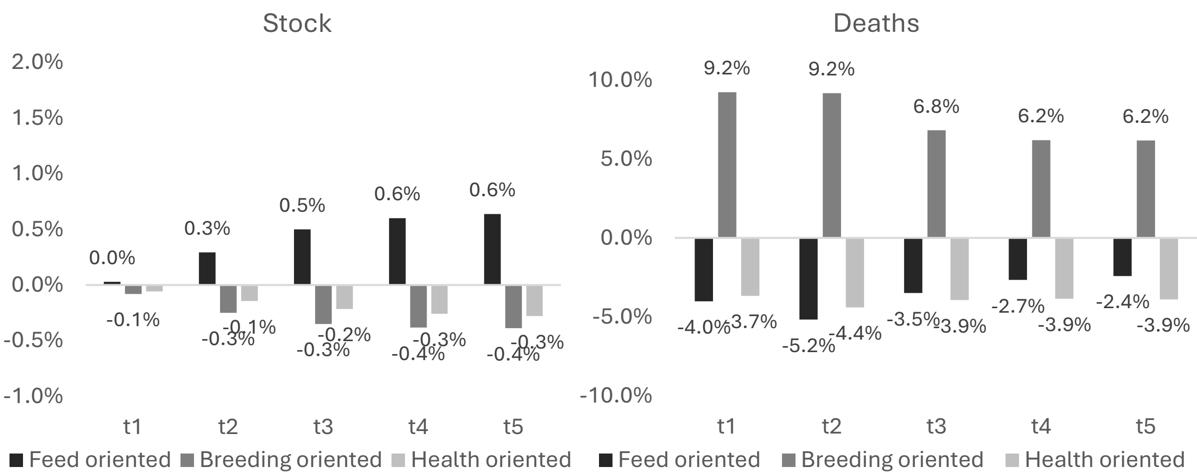
A) Percentage point deviations in meat and milk yield growth



B) Percentage point deviations in meat and milk output growth



C) Percentage point deviations in animal stock and deaths



Births, deaths, and offtake rates are the key determinants of stock size. Panel C demonstrates that animal deaths exhibit more volatility and responsiveness to the various intervention and spending options than stock size changes. In the breeding-oriented scenario, deaths are significantly higher, which leads to stagnation in stock size over time. However, this intervention gradually shifts the herd composition toward more productive breeds, a shift reflected in the strong milk yield response starting from t_4 in Panel B. On the other hand, both the feed- and health-oriented spending options effectively reduce annual deaths by over 2.4 and 3.7 percentage points, respectively. These reductions in mortality contribute to stock growth, although their influence on the overall stock size is moderated by the system's carrying capacity and other constraints.

7 CONCLUDING REMARKS

The livestock sector plays a crucial role in supporting agricultural development, food production, and nutritional security, particularly in developing countries where smallholder producers rely on it for a significant portion of their livelihoods. However, as global population grows, particularly in regions facing rural poverty and hunger, the sector faces increasing pressure to meet rising demand. While governments and development agencies in developing countries have been implementing various strategies to strengthen the livestock sector, these efforts have not been fully evaluated in terms of their impact on improving livestock performance. By situating livestock dynamics within an economywide framework, this research assesses the relative cost-effectiveness of different intervention options (feed, breading, health) and budget allocation strategies (balanced, feed oriented, breeding oriented, and health oriented) using the case of Rwanda as example.

In relation to impacts on <u>selected economic outcomes</u>, the analyzed interventions show moderate but sustained impacts on agricultural GDP and significant effects on the livestock sector. The *balanced spending scenario* shows that breeding has the largest individual influence, contributing 0.4 percent immediately and 0.6 percent cumulatively to agricultural GDP, emphasizing its role in boosting productivity. In the livestock sector, the interventions jointly lead to an immediate 6.5 percent GDP impact, with breeding contributing to close to half of this gain. The cumulative effect rises to 8.6 percent, again driven primarily by breeding interventions, while feed interventions have a smaller overall impact. Of the sub-components of feed, improved feed has stronger immediate and cumulative effect on various livestock activities. Dewormers are the health interventions that yield significant long-term productivity gains.

The *biased spending scenarios* do not alter the impact on the agricultural sector significantly. However, effects on livestock and its sub-components markedly vary. Breeding-oriented spending initially outperforms, boosting milk sector GDP by 1.9 percent and dairy processing by 1.0 percent. Health-oriented spending excels in cattle and meat GDP due to reduced deaths and increased liveweight. The cumulative impacts over the spending period grow larger as interventions, particularly breeding, take time to fully influence meat and milk yields.

On the <u>livestock system outcomes</u>, combined *balanced spending* on feed, breeding, and health interventions results in a 12.5 percent increase in meat yield by the end of the simulation period, with each intervention contributing differently. Feed and health measures show immediate positive effects, while breeding initially reduces meat yield due to herd expansion but leads to gradual recovery as more productive breeds are integrated. For milk yield, the combined intervention shows no significant effect initially due to herd growth limiting per capita feed availability, but later results in a 27 percent increase, largely driven by breeding. Dewormers are the health interventions which notably enhance both meat and milk yields.

We also find that meat production is significantly driven by the health interventions while breeding boosts milk production, especially in the later period. Improved feed and dewormers are more effective in increasing production compared to fodder and vaccines, which mainly reduce animal deaths but slow yield growth. Further, the interventions modelled jointly accelerate herd growth by 2.4 percentage points, with improved feed playing a crucial role by reducing forced offtake and mitigating feed shortage-induced deaths. However, breeding and health interventions alone fail to sustain herd growth due to feed constraints.

Of the *biased spending* scenarios, health-oriented spending, driven by deworming interventions, leads to the most sustained meat yield growth, surpassing the balanced scenario by over 4.5 percent. Conversely, both feed- and breeding-oriented spending initially underperform, though the latter recovers as breed improvements materialize, boosting meat yield over time. For milk yield, feed and health-oriented spending show early gains, but the feed scenario weakens due to increased stock size and stagnant breed quality. Breeding-oriented spending eventually surpasses the balanced scenario in milk yield by improving herd composition.

In terms of output, health-oriented spending outpaces the balanced scenario in meat production, growing 3.5 percentage points faster, though milk output gains remain modest. Feed- and breeding-oriented options contribute less to overall output, with the feed scenario hindered by lower slaughter rates due to increased feed availability. Meanwhile, feed-oriented spending supports the strongest stock growth by mitigating feed shortages, while breeding and health interventions are limited by system constraints. Death rates respond more to these interventions than stock size, with feed- and health-oriented spending reducing deaths markedly.

Our findings contribute to the broader literature by offering insights into the potential impact of alternative interventions and spending options on economic and livestock systems performance in low-income contexts, particularly in countries like Rwanda, where existing research is limited. These results are intended to inform policymakers as they seek to revitalize the livestock sector and enhance its resilience to future challenges.

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