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Modeling Crop-Livestock Interactions in Semi-subsistence Economies

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ABSTRACT

Climate and weather shocks pose significant threats to crop-livestock systems, leading to economic losses and humanitarian crises. Utilizing a modeling framework that innovatively integrates the crop and livestock systems, this study examines the interactions and dynamic adjustments within these systems following weather shocks, using Ethiopia as a case study. We also evaluate the effectiveness of various adaptation strategies in sustaining farm incomes, food security, and welfare. Results show unique effects on the crop and livestock sectors resulting from a joint shock on the two systems. While food crops experience a strong and immediate growth effect that fades quickly, the livestock sector faces the full impact of the shock a year later, with the effect persisting to some degree. We also find diverging economic and livestock system adjustment trajectories from the separate shocks to the crop and livestock systems. Further, the intervention options analyzed show contrasting impacts on various outcome indications, with only the resilient crop intervention causing sector-indifferent impacts. Our findings emphasize the importance of proactive measures to enhance the resilience of crop-livestock systems, with implications for policy and practice aimed at safeguarding food security and livelihoods in semi-subsistence economies.

Keywords: Weather shocks, crop-livestock systems, dynamic adjustments, integrated framework, Ethiopia

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1 INTRODUCTION

Globally, crop-livestock systems play a crucial role in food production, accounting for over 90 percent of the world's milk supply and 80 percent of meat from ruminants (Thornton and Herrero, 2014). These integrated systems are vital for livelihoods and food security, especially for the poor, as they provide most of the food consumed by the poor. Typically, these systems are interlinked, with products or by-products from one activity, such as crop residues or raw feed, utilized by the other, such as animal production. In return, animal production provides inputs like traction or manure back to the cropping activity. As the global population rapidly increases, particularly in the developing world where rural poverty and hunger are concentrated, crop-livestock systems will face significant pressure to perform robustly and meet the growing demand for food.

Crop and livestock systems are particularly vulnerable to the effects of climate change, and their interaction amplifies the impacts, leading to significant and often irreversible consequences. In East Africa, there has been a notable increase in below-normal rainfall years since 2000, with over nine widespread occurrences recorded in 1998, 2000, 2005/2006, 2007, 2008, 2009, 2011, 2016/2017, and 2022 (Nicholson, 2014; Palmer et al., 2023). Predictions suggest that the frequency and severity of droughts and other climatic extremes will worsen in the coming years (Godde et al., 2021; Thornton and Herrero, 2014; Palmer et al., 2023). Numerous studies have demonstrated significant short- and medium-term economic losses in the region, including country-level analyses by Mera (2018), Siddig et al. (2020), and Speranza (2010), as well as regional assessments by Davies and Wroblewski (2014) and Palmer et al. (2023). Additionally, Sohnesen (2020), Hirvonen et al. (2020), and Singh et al. (2016) investigated the impact of the 2016 drought in Ethiopia using various methods of analysis. The humanitarian toll of such disasters is also profound (Maystadt and Ecker, 2014; Lewis, 2017).

Despite the considerable importance of crop-livestock systems, the likely impact of climate-induced shocks on their interaction remains poorly understood from a developing country perspective (Thornton and Herrero, 2014). Furthermore, the impact of their close interaction on the recovery dynamics has not yet been thoroughly researched, although it is anticipated that the magnitude of losses and the speed of recovery from a weather shock will differ between these systems.

Various strategies enable these systems to adapt to climate change and enhance their resilience. For the crop sector, interventions might involve promoting drought-resistant varieties and implementing modern farming practices. Similarly, the livestock sector could adapt by employing herd size management practices, such as early restocking following a shock. Policy measures could also support both sectors, including targeted expansion and reallocation of land for crop or feed production, to list a few.

This study evaluates crop-livestock interactions and dynamic adjustments following a commonly observed weather shock in a typical developing economy, using Ethiopia as a case study. Additionally, it assesses the importance of various crop and livestock adaptation strategies in sustaining farm incomes, food security, and welfare. The study utilizes a modeling framework that incorporates environmental and climate change factors into its forage supply function and considers animal traction as a capital factor in the crop sector. The model is calibrated for the five agro-ecological zones in Ethiopia.

Our research contributes to the analysis of drought impacts on crop and livestock systems in several critical ways. Firstly, we elucidate the various channels through which weather shocks, such as droughts, influence both the crop and livestock sectors. Secondly, we utilize a dynamic integrated economic and animal systems model to estimate drought impacts over a defined analysis period within the broader economic context. While some studies focus solely on the crop or livestock sector separately (Hasegawa et al., 2022; Schierhorn et al., 2020; Bernabucci, 2019; Acosta et al., 2021) and others (Leister et al., 2015; Thornton and Herrero, 2014; Countryman et al., 2016) consider the crop-livestock interaction in a partial equilibrium setting, our approach captures their interdependence within an economywide framework, offering a more comprehensive understanding. Thirdly, we uncover differences in the dynamic adjustment processes between the crop and livestock systems in Ethiopia when climate shocks affect these two major agricultural sub-sectors differently. This aspect has been largely neglected in existing literature on drought impacts (Leister et al., 2015).

Although drought-related shocks affect both the livestock and crop sectors, the temporal adjustments manifested by these sectors differ significantly. While the crop sector may experience an immediate and direct reduction in activity during drought periods and adjust relatively quickly, livestock-related primary and processing activities may take longer to fully feel the impact of the shock and require more time to adapt. Previous studies, such as Leister et al. (2015), Cheng et al. (2023), and Countryman et al. (2016), have documented a lagged effect on meat production, primarily due to increased drought-induced culling followed by subsequent restocking efforts. Additionally, animal numbers are likely to decline significantly due to increased sales and slaughtering, as well as animal deaths resulting from feed shortages and heightened vulnerability to diseases.

The importance of understanding the impacts of droughts in agrarian economies is well-documented in the literature. Studies such as those by Hasegawa et al. (2022) and Schierhorn et al. (2020) focus on examining how drought affects crop yields. Others, including Godde et al. (2021), Aragie and Thurlow (2021), Bernabucci (2019), and Countryman et al. (2016), delve into the dynamics of the livestock sector and its response to climate variability. Furthermore, works by Godde et al. (2021) and Acosta et al. (2021) explore the various socioeconomic factors that influence the impacts of climatic shocks in developing countries. While these studies provide valuable insights into the topic, our research adds to this body of knowledge by elucidating how the interaction between crop and livestock systems shapes the recovery dynamics of both sectors and the broader economy, as well as their welfare implications in low-income economies by employing a framework that integrates economic and livestock systems.

To achieve these objectives, this study proceeds as follows. First, we provide an overview of Ethiopia's crop and livestock systems, highlighting the production and consumption patterns of crop and livestock products, as well as the geographic distribution of cattle. Second, we outline the analytical method used to investigate crop and livestock interactions, detailing the integrated economic and animal system model and the key parameters influencing the outcomes. Subsequently, we discuss the drought-related shocks simulated for the livestock and crop sectors, along with the alternative intervention scenarios considered. The results section presents findings from both the economic model and the animal systems model, examining the effects of a one-time shock with and without interventions. Finally, we summarize the key conclusions drawn from this study.

2 ETHIOPIA'S CROP AND LIVESTOCK SYSTEMS

Endowed with a population of over 120 million, Ethiopia is home to 77 million people directly relying on agriculture as a source of livelihood (World Bank, 2024). Over 12 percent (14 million) of Ethiopians reside in agro-pastoral lowlands (Tofu et al., 2023), which are commonly arid or semi-arid and sparsely populated spanning over 61 percent of Ethiopia's total land mass (Mohamed, 2019). In 2017, there were about 15.7 million farm households, or peasant holdings, engaged in grain crop production, along with over 13.7 million holdings raising cattle (CSA, 2018a). Poverty remains pervasive, with 24 percent of the population living below the national poverty line as of 2015 (World Bank, 2024).

Broadly speaking, Ethiopia's dominant agricultural systems comprise mixed agriculture in the highlands, characterized by integrated crop and livestock production, and pastoralism in the lowlands, where food crop production plays a peripheral role. The crop sector contributes to over 62 percent of gross output (see Table 1), with food crop production alone accounting for 42 percent. Approximately 38 percent of this output is consumed domestically by semi-subsistence farm households, without reaching the market. Notably, the highlands alone generate 97 percent of the total crop output.

Table 1. Crop and livestock production and consumption patterns in Ethiopia (in bil. Birr)

Agro-ecological zone	Crop gross output			Livestock gross output		
	Total output	Food crops	Share of own consumption	Total output	Cattle sector	Share of own consumption
Dry_high	109.2	84.9	29.1%	78.6	65.5	41.9%
Moist_cereal	250.9	195.8	25.2%	130.4	115.4	42.1%
Moist_enset	75.9	23.3	37.1%	42.3	38.1	42.2%
Dry_low	4.8	1.1	6.4%	11.0	7.3	41.6%
Moist_low	7.7	2.6	17.6%	12.1	9.8	41.9%
Total	448.6	307.7	27.9%	274.5	236.2	42.1%

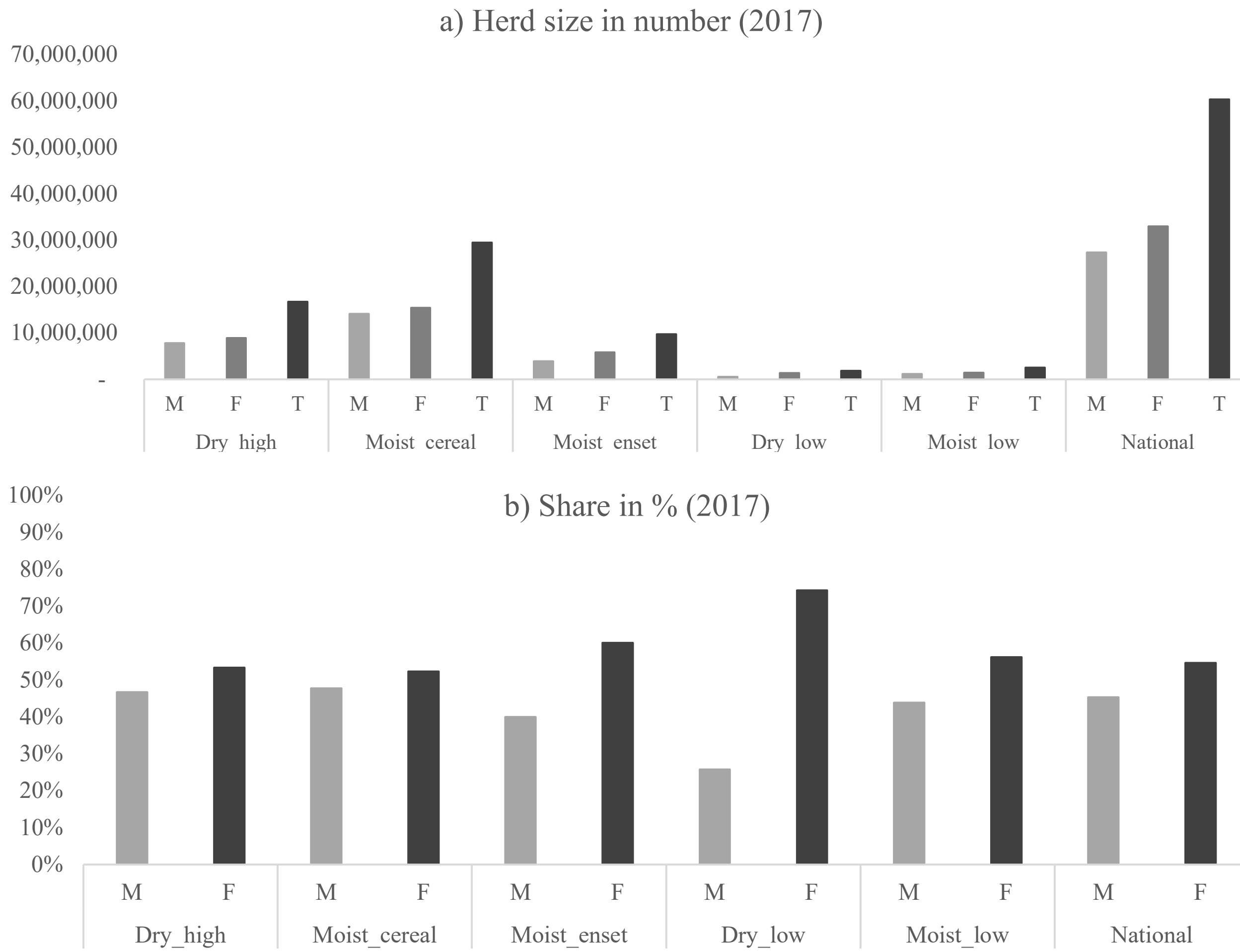
Note: *Dry_high* = drought prone highlands, *Moist_cereal* = cereal-based moisture sufficient highlands, *Moist_enset* = *enset*-based moisture sufficient highlands, *Dry_low* = drought prone lowlands, and *Moist_low* = moisture sufficient lowlands.
Source: Aragie and Thurlow (2021)

In contrast, livestock is the primary economic activity in the lowlands of Ethiopia, contributing to 65 percent of gross agricultural output (86 percent when non-food crops are excluded). Livestock also remains significantly relevant in the mixed agriculture areas of the highlands. Consumption of livestock products for own use is notably high across the country and irrespective of agro-ecology, indicating the underdeveloped nature of animal source food value chains.

To examine the initial structure of the Ethiopian cattle population, which ranks as the largest in Africa with over 60 million heads, we analyzed the 2017 livestock survey data (CSA, 2018), which was also utilized to calibrate the herd dynamics model discussed in section 3.2. The survey reveals a significant disparity in the spatial distribution of cattle herds. Approximately half of the Ethiopian cattle population is concentrated in the cereal-based humid highlands, primarily due to the high concentration of rural population in these areas where farming-livestock interaction is robust (Dorosh et al., 2018). Drought-prone highlands follow distantly behind, accounting for 28 percent of the total cattle population.

The proportion of females in the total cattle population is slightly higher both at the regional and national levels (Figure 1). However, the male-to-female ratio varies significantly across agro-ecological zones, ranging from 26:74 in dry lowlands to 48:52 in cereal-based humid highlands. This divergence in the sex distribution in the humid highland and pastoralist areas has strong rationality behind it. In the cereal-based highlands of Ethiopia, crop production dominates agricultural practices, and farmers rely on cattle draught power for tillage. In fact, according to CSA (2018), close to 60 percent of male adult cattle at the national level are utilized for draught. On the other hand, pastoralists usually keep their female cattle stock for milk and reproduction, while they sell the male cattle to generate income for buying food and covering other expenses.

Figure 1. Baseline number and share of Ethiopia's cattle by agro-ecology zones



Note *Dry_high* = drought prone highlands, *Moist_cereal* = cereal-based moisture sufficient highlands, *Moist_enset* = *enset*-based moisture sufficient highlands, *Dry_low* = drought prone lowlands, and *Moist_low* = moisture sufficient lowlands. M = Male, F = Female, and T = total.
Source: CSA (2018)

The livestock sector in Ethiopia has been encountering significant challenges attributed to weather shocks, leading to notable and recurrent declines in animal numbers. However, the intensity and frequency of these shocks vary across different agro-ecological zones. Analysis of livestock survey data spanning from 2005 to 2019 indicates that the lowlands have been particularly hard-hit, experiencing frequent shocks ranging from 7 to 50 percent in magnitude during five of the past 15 years. It is worth noting that our analysis does not encompass the 2003/04 drought, which remains one of the costliest and extensively researched droughts in the country's recent history (Admassu et al., 2007).

Notably, the humid lowlands experienced significant declines in cattle stock of 11 to 50 percent in 2005, 2006, and 2011, while the humid highlands in cereal-based Ethiopia faced a 6 percent decline in stock in 2018. Additionally, *enset* (false banana)-based humid highlands and drought-prone highlands experienced an 8 and 5 percent decline in 2012, respectively, while drought-prone lowlands saw declines of 8 and 22 percent in 2005 and 2017. In several instances, a second round of drought shock occurred before the livestock numbers could recover to their pre-shock levels, exacerbating the situation. For example, the cattle number in humid lowlands only recovered to the 2009 levels by 2016, and the stock size in *enset*-based humid highlands of Ethiopia did not recover to the 2011 levels until 2018. Similarly, cattle numbers in dry lowlands never rebounded to their 2015 levels.

3 METHOD OF ANALYSIS

3.1 A framework of crop and livestock systems interactions

The study's conceptual framework divides the agricultural system into the crop system and the livestock system, exploring their interdependence through input and output flows within an integrated crop-livestock system operating under specific ecological conditions in tropical Africa. A range of crops, including cereals, pulses, oilseeds, root crops, and perennial crops, constitute the crop farming system. The livestock system encompasses both large and small farm animals, focusing particularly on cattle. These two systems are integrated within the farming system, albeit to varying degrees spatially. Figure 2 illustrates the interaction between the two systems.

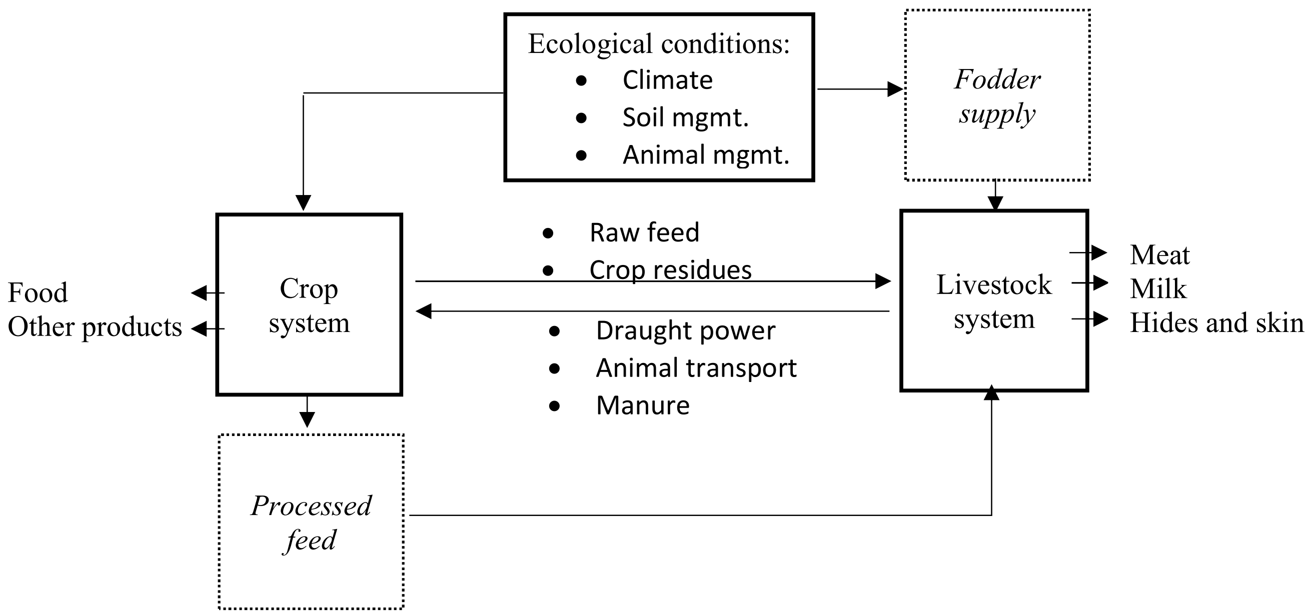
An integrated crop-livestock system is recognized as a sustainable agricultural approach that contributes to enhancing food security (Thornton and Herrero, 2014; Sekaran et al., 2021). For instance, the livestock sector can generate effective demand for raw feed, such as maize and soybeans, as well as crop residues. Additionally, the crop sector provides essential inputs for manufacturing processed feed. In regions where smallholder agriculture predominates, traditional feed sources—primarily open grazing—remain prevalent, with improved feed practices more commonly adopted in urban and peri-urban settings.

Conversely, livestock contribute to the crop sector by providing animal traction, serving both draught power and transport services, particularly in areas where the use of motorized machinery is limited among farm households (MoFED and MoA, 2011; Wilson, 2003). Estimates of the number of animals used for power applications globally range from 300 million upwards, with oxen the most frequently used (Wilson, 2003). Livestock further plays a crucial role in supplying manure, which helps improve soil fertility—an essential aspect given the poor soil conditions prevalent in many areas due to improper cultivation practices, erosion, and nutrient imbalances. The long-standing practice of utilizing manure has been instrumental in boosting crop production, enhancing soil organic matter, and fostering soil fertility (Thornton and Herrero, 2014; Sekaran et al., 2021).

However, this interlinkage could also pose risks, as an ecological condition affecting one system may propagate to the other through input-output interdependencies. In addition to their perceived complementarities, there is potential for competition for resources such as water, land, and the utilization of crop residues as feed, which could otherwise be used for mulch and soil nutrient replenishment.

The operations of both the crop system and livestock system are deeply influenced by ecological conditions, encompassing factors such as climatic variations, agronomic practices, and herd management strategies. Climate change presents substantial challenges to these systems, amplifying existing vulnerabilities across diverse agro-ecological zones and impacting crop yields and fodder availability. To mitigate these challenges, efficient soil management, planting techniques, and herd and grazing management practices are crucial. They not only support crop and livestock productivity but also ensure sustainability and promote long-term viability of agricultural activities.

Figure 2. A framework of crop and livestock systems interactions



Source: Own compilation

3.2 The Herd Dynamics Module (HDM)

The analytical framework innovatively adopted in this study constitutes a robust Herd Dynamics Module (HDM) developed (Aragie et al., 2021) in the spirit of Lesnoff (2009-2013) but provides a well-disaggregated presentation of age cohorts and agro-ecology. The HDM, governing the livestock system, is a lifecycle module that tracks annual herd size categorized by age, sex, breed, and agro-ecology. It also captures stock-flow relationships that depict deeper economic logic. In addition, it incorporates several cattle sector related demographic parameters and activities, including offtakes (sales of live animals) and production of various livestock products (e.g., meat and milk).

A few policy interventions are also embedded within the HDM, such as public provision of medicines to enhance animal health or access to improved feed to boost on-farm livestock productivity. Environmental variables, such as forage supply and biophysical carrying capacity, are incorporated to capture the impact of weather variability on herd stock levels and productivity. The HDM further incorporates a range of parameters and variables for analyzing shocks such as droughts, disease outbreaks, and other impactful events affecting the livestock system (e.g., Aragie and Thurlow, 2022).

The HDM used in this study is calibrated to historical data from the livestock module of Ethiopia's Agricultural Sample Surveys (CSA, 2004-2018) and information from past studies on the livestock system (Shapiro et al., 2017). We specifically build the cattle database separately for the (i) drought-prone highlands (Dry_high), (ii) cereal-based moisture sufficient highlands (Moist_cereal), (iii) the wild African banana relative crop, *enset*-based moisture sufficient highlands (Moist_*enset*), (iv) moisture sufficient lowlands (Moist_low), and (v) drought-prone lowlands (Dry_low) agro-ecological zones of the country.

Unlike many other HDMs that rely on broader age cohorts (Msangi et al., 2014; Lesnoff, 2009–2013), we build a single-year age cohort cattle HDM. Constructing a single-year age cohort-specific demographic structure is useful for many reasons. Firstly, the fundamental demographic parameters (death and offtake rates) widely differ by age. Secondly, this enables researchers to better understand changes in the age composition of the herd and design age-specific measures for a stable herd population.

3.3 Links to the crop sector and the wider economy

The economic system is governed by a recursive dynamic computable general equilibrium (CGE) model known as IFPRI's Rural Investment and Policy Analysis (RIAPA) model. This model has been extensively utilized for examining agricultural policies and investments (Pauw and Thurlow, 2015; Benfica et al., 2019), as well as other socioeconomic policies (Burns et al., 2013; Aragie et al., 2018). RIAPA incorporates both behavioral equations, which depict economic decisions such as production, marketing, and consumption, etc., made by economic agents such as firms, households, and other institutions, and structural equations that define the accounting relationships between the incomes and expenditures of individual agents and within the macroeconomy. Within this model, production is characterized by a multi-level nested structure defined for each sector, featuring fixed input-output relationships and variable factor use governed by a constant elasticity of substitution (CES) technology function.

Household consumption constitutes both marketed commodities and home-produced goods. Demand for commodities by representative households is determined using a linear expenditure system (LES), where minimum quantities of each commodity represent "subsistence" consumption and remain unaffected by price changes. The remaining portion of consumption expenditure is considered "discretionary" and responds to relative price or income changes. Within the model framework, market prices adjust to ensure overall national supply and demand equilibrium for each product.

Within this recursive dynamic framework, the model updates certain parameters between periods based on long-term trends and future outlooks to reflect changes in factor supply and productivity, population growth, government spending, and inflows of foreign capital. Additionally, capital stocks within each sector and region are updated annually to reflect depreciation and investments made in the previous period.

One novel feature of the integrated approach adopted in this study is the systematic link between the HDM and the economic model. By leveraging data on consumer demand for animal products and assessing the relative profitability of animal offtake activities derived from the economywide model, the HDM recalibrates new offtake levels and the remaining herd size.

In the livestock system model, animal feed encompasses raw feed, processed feed, crop residues, and fodder. Based on the performance of the crop and feed processing sector, the economic model recalculates feed supply each year. Moreover, the HDM also incorporates a potential grass growth function[1] that determines fodder supply subject to a composite index incorporating precipitation and temperature data. Fluctuations in per capita feed availability within the livestock system subsequently impact milk and meat offtake per head, as well as the system's carrying capacity. Offtake rates are responsive to changes in carrying capacity; for instance, during periods of reduced per capita feed availability due to adverse weather conditions or crop output shortfalls, farmers may opt to selectively sell or slaughter animals, leading to adjustments in herd size, composition, and milk and meat production over time. Additionally, the HDM features a mechanism linking per capita feed availability to death rates.

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[1] The potential grass growth (GP) function is a mathematical model used to estimate the potential growth of forage or fodder plants under specific temperature and precipitation conditions. These functions have been used in grass growth analysis and are incorporated in some of the long-established ecosystem response models such as the CENTURY model (Parton et al., 2005). The GP function introduced within the HDM follows: $GP = 0.5 * EXP\left(-0.5 * \left(\frac{T_t - \bar{T}}{T_{max} - T_{min}}\right)^2\right) + 0.5 * EXP\left(-0.5 * \left(\frac{P_t - P}{P_{max} - P_{min}}\right)^2\right)$, where T is temperature and P is precipitation. In the simulations, the GP coefficient is iteratively reduced to achieve the level of cattle deaths due to per capita feed shortage.

The dynamics within the livestock model are intricately connected to the economic model through the annual growth rate in livestock capital within specific subsectors (such as cattle and milk) and traction capital within the crop sector. As the economic model iteratively solves for successive years, the livestock capital within the cattle sector is updated annually based on the growth rate in meat offtake computed in the HDM. Similarly, livestock capital within the milk production sector in the economic model updates in response to the growth in milk offtake from the HDM. Traction serves as another nexus of interaction between the livestock system and the crop system. Following adjustments for new births, deaths, and offtake rates, the HDM calculates the growth in male cattle numbers, which governs the progression of traction capital over time.

In this study, we track shifts in sectoral and national gross domestic product (GDP), poverty rates, and diet diversity resulting from simulated drought-induced alterations to the performance of both the crop and livestock sectors. Additionally, we assess adjustments in critical indicators derived from the HDM for Ethiopian cattle. While changes in sectoral and national GDP are obtained from the aforementioned economic model, adjustments in poverty rates and diet diversity outcomes are estimated using microsimulation modules linked top-down with the economics model.

Numerous studies (Diao et al., 2008; Bezemer and Headey, 2008; Latino et al., 2020) emphasize that the performance of the crop and livestock sectors in developing economies significantly influences poverty and diet quality outcomes. Changes in poverty are computed by integrating a poverty microsimulation module with the CGE model outcome variables, including household income, prices, and consumption, following the approach of Arndt et al. (2012). Changes in real consumption across commodities in the CGE model are transmitted to respective households using data from the 2010/11 Household Consumption Expenditure (HCE) survey (CSA, 2012), which corresponds to the 15 representative household groups in the CGE model. New poverty statuses are then computed for all sampled households. Similarly, changes in diet quality are estimated using a microeconomic module extensively discussed in Pauw et al. (2023). This module calculates alterations in the quality of a household's diet based on consumption gaps between a reference diet and the household's current diet. Like the poverty module, this component also utilizes data from the 2010/11 HCE survey, linking households to their respective representative household groups in the CGE model.

3.4 Regionalizing agriculture data and valuing oxen draft power

The RIAPA model utilized in this study is calibrated to a modified version of the 2017 Social Accounting Matrix (SAM) for Ethiopia (Aragie and Thurlow, 2021), which features a comprehensive account structure. This structure includes 80 commodities (31 in agriculture), 13 factors of production (such as labor, land, and agricultural and non-agricultural capital), and 15 representative farm and non-farm households categorized by expenditure quintile. Eight of the sectors in this Ethiopian model are livestock-related, encompassing primary and processing sectors.

The SAM was modified to accurately represent the regional features of agriculture in the country. This was achieved by integrating data from CSA (2018, 2018a), which provides zonal-level information on crop and livestock production. Consequently, the revised SAM distinguishes 31 agricultural activities further disaggregated by agro-ecological zones, along with 18 agro-processing sectors, resulting in detailed agri-food sectors. The SAM reveals that livestock contribute approximately 29 and 57 percent of agricultural GDP in the highlands and lowlands of Ethiopia, respectively.

Valuing the contribution of livestock capital in the non-livestock sector has posed challenges, primarily due to data limitations. Consequently, it is uncommon for livestock to be adequately accounted for as a capital input in the crop sector within most economywide databases and models for developing countries. To address this gap, we customize the SAM for Ethiopia (Aragie and Thurlow, 2021) discussed above to incorporate the significance of oxen as a source of animal traction for land preparation, acknowledging their pivotal role in the country's current production system. According to CSA (2018), there are over 7.6 million pairs of oxen providing draft power.

To compute the value of livestock used for ploughing in the crop sector, we relied on data regarding the number of oxen employed for this purpose, the average number of days they were engaged per year, and the corresponding rental rate per day. This valuation was achieved by multiplying the reported number of pairs of oxen used for ploughing, sourced from CSA (2018), by the 2018 equivalent national average rental value, and the average number of days spent by oxen in land preparation, as documented by MoFED and MoA (2011). These organizations referenced previous studies that reported oxen workdays averaged 60 per year in Ethiopia, with an average rental value of Birr 40.0 per pair of oxen in 2011. Comparable figures for the number of days were also found in Gryseels et al. (1984) and Wilson (2003). It is essential to clarify that the livestock capital considered in the model excludes activities like trashing after harvest and transportation services provided by animals.

Once the value of livestock capital in the crop sector GDP is determined as explained earlier, we subtract this value from land and other agricultural capital, under the assumption that three-fourths of crop sector capital in the current SAM constitutes livestock capital, while the remainder of livestock capital is embedded in land. This explicit presentation of livestock capital in crop sector GDP shifts the share of land from 89 percent to 78 percent of crop GDP, and the share of other capital in the crop sector from 11 percent to 3 percent. This adjustment is justified given that semi-subsistence households in Ethiopia typically rely on rudimentary agricultural tools such as traditional wooden ploughs, neck yokes, and a pair of oxen for ploughing, with limited access to other forms of capital inputs in the crop sector.

4 SCENARIO DESIGN

In this study, we design three major sets of scenarios: (i) the baseline scenario, (ii) the crop and livestock droughts shock scenarios, and (iii) the intervention scenarios. To establish a benchmark against which the drought scenarios are assessed, we first formulate a baseline scenario that reflects the typical performance of the crop and livestock sectors, as well as the overall economy, under normal conditions. In the baseline scenario, we assume the recent past growth trend is maintained, where the crop and livestock sectors grow by 6.5 and 8.0 percent, respectively, resulting in an overall GDP growth of just under 7 percent. The model estimates the economic and livestock systems over a five-year period (*t1*-*t5*), which is deemed sufficient for the system to return back to the long-term growth trajectory.

4.1 Crop and livestock under drought

Drought (crop and livestock): This scenario considers a one-time shock to both the crop and livestock systems. We introduce an average 20 percent yield shock to cereals, pulses, and oilseeds jointly with a comparable shock to the livestock system, resulting in a 20 percent reduction in initial cattle stock. The 20 percent decline in crop yield mirrors a low-end yield shock observed during one of the highly documented droughts in Ethiopia, i.e., that of 2003, and is strong enough to reveal the interlinkage and dynamics of the crop and livestock systems in the country. Similarly, declines of more than 20 percent in cattle herds have been documented in various parts of the country in previous years, notably in 2006, 2011, and 2017 (CSA, 2004-2018). The shock to the livestock system is implemented within the HDM through a reduction in per capita feed availability, which – through carrying capacity adjusted cattle offtake and death rates – determines the final stock level. Forage production, contributing to 60 percent of the feed supply in Ethiopia's cattle system (CSA, 2018), is decreased by 35 percent, alongside endogenous adjustments in the raw and processed feed sectors from base levels, to achieve the 20 percent reduction in herd size. Meanwhile, the shock to the crop sector is implemented within the core economic model by altering crop sector productivity.

Drought (crop only): This hypothetical scenario is designed to explore the linkage effect of a weather shock to the crop sector, assuming the livestock sector remains directly unaffected by the shock. While this scenario may seem impractical, as climatic and weather shocks affecting one sub-sector of agriculture often impact the other, it enables us to analyze how differently the crop and livestock sectors adjust after such an isolated shock and examine the differential effects on other agricultural subsector (e.g., the pass-through effect of a shock to the crop sector on livestock). In this scenario, similar to the joint shock scenario above, we imposed a 20 percent reduction in crop sector productivity, leaving the livestock system directly unaffected.

Drought (livestock only): Similarly, we introduced a scenario where only the livestock sector is directly affected by the weather shock. As in the crop-only scenario, we implement a 20 percent shock to the cattle herd. In the joint crop and livestock system shock scenario, the impact pathways to livestock stem from both the effect on the crop sector and directly on the stock of animals, as modeled by the HDM. In this scenario, we only consider HDM channels.

4.2 Crop and livestock interventions

This set of scenarios captures the various ways in which the crop and livestock systems adapt to drought shocks.

Restocking: This is one of the four intervention scenarios we assess. This scenario involves herd management aimed at rapidly rebuilding the herd after a drought shock. We assume that farmers aggressively restock their herds over two years following the drought. This scenario is implemented by halving the offtake rate, i.e., slaughtering rate, across the herd.

Grazing land: Currently, approximately 1.8 million hectares of land in Ethiopia are designated for grazing, while 14.5 million hectares are used for crop production (CSA, 2018a). Under this scenario, we envision a 6 percent faster expansion in grazing land annually in Ethiopia, aiming to improve access to animal feed. This expansion is at the expense of reduced farmland, assuming the total land supply remains fixed. Consequently, there is an equivalent 0.5 percent annual reduction in crop land. This intervention is implemented when both the crop and livestock systems face the drought shocks defined in the joint crop and livestock system shock scenario.

Crop land: The final two scenarios relate to sustaining the performance of the crop sector amid weather variability. Similar to the grazing land scenario, the crop land scenario considers an increase in farmland that occurs at the cost of grazing land. Specifically, there is a 0.5 percent further increase in crop land annually, matched by a 3.5 percent reduction in grazing land. This reallocation of grazing land to crop production occurs while the livestock system faces weather-induced shock.

Resilient crop: In the resilient crop scenario, we mitigate the impact of the drought shock on crops by halving the simulated yield effect. This resilience could be achieved through more informed planting decisions and better access to drought-resistant crop varieties. However, we maintain the shocks to the livestock system, as assumed in previous scenarios.

5 RESULTS AND DISCUSSION

First, we analyze the results from crop and livestock drought scenarios in comparison with the baseline trend. Next, we explore the role of various interventions in altering the impacts of drought on economic and livestock systems, as well as on their recovery dynamics, using the joint crop and livestock scenario as a basis.

5.1 Impacts of drought

In the baseline scenario, the Ethiopian economy follows the recent trend of 6.5 percent growth per year (Annex Table A1). Annex Table A1 further shows that the joint crop and livestock shock causes an overall GDP decline of 3.6 percent compared to the baseline trajectory during the year of shock (year *t1*). The growth effect of the one-time shock persists until the end of the third year (year *t3*). However, although growth recovers back to the trend level by *t5*, GDP remains 5.4 percent lower than the baseline - or no shock- scenario, with considerable repercussions on poverty (see Figure 4). The impact on GDP is particularly severe in the agricultural sector, with an immediate reduction in growth of 9.5 percentage points, followed by a 5.4 percentage point reduction in the subsequent year (Panel A, Figure 3). This is because the sector experiences the direct and substantial consequences of the simulated weather shock.

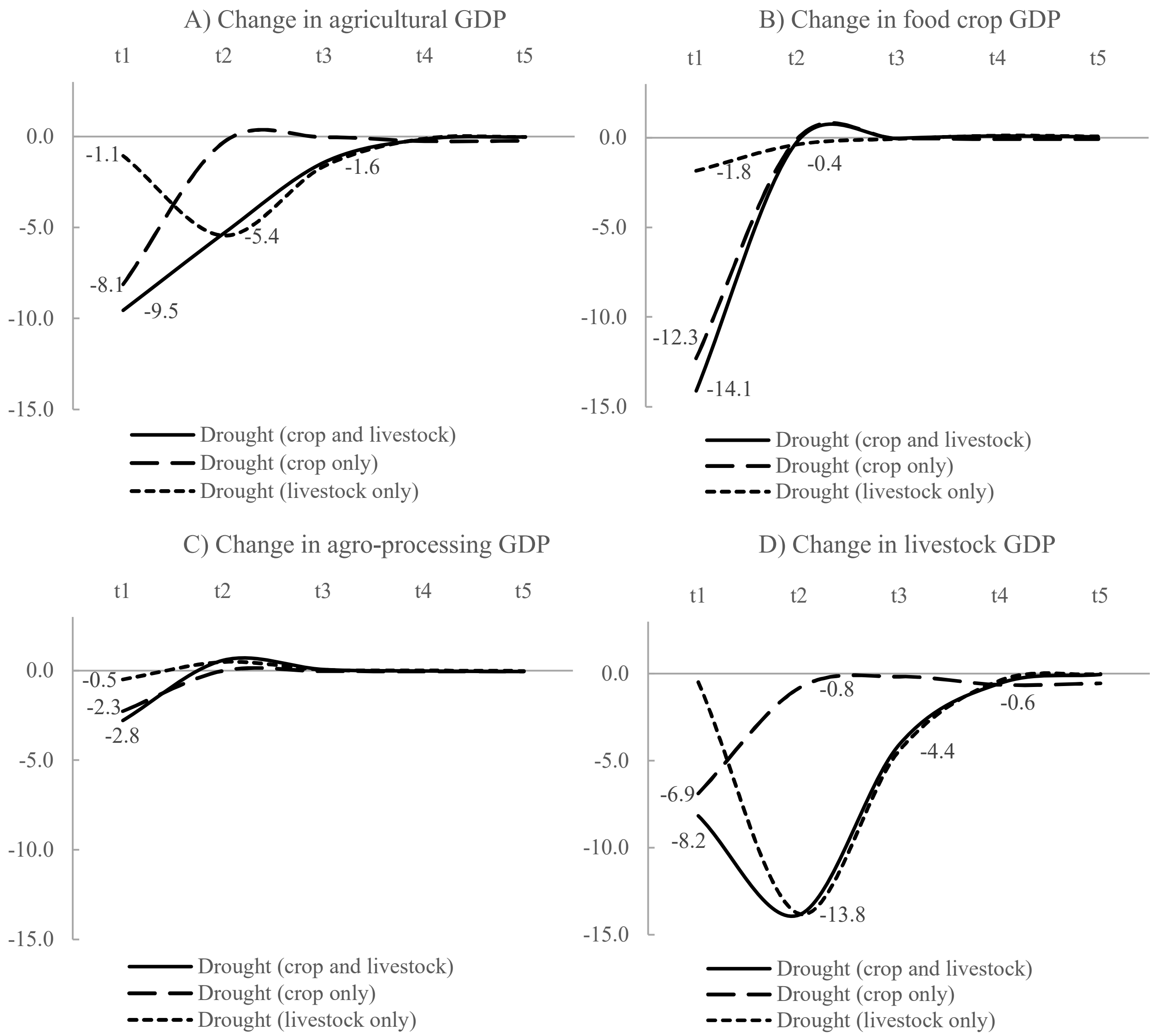
We further observe unique effects on the crop and livestock sectors resulting from the joint shock on the two systems. While food crops experience a strong and immediate growth effect that fades by the following year (Panel B), the livestock sector faces the full impact of the shock a year later, with the effect persisting to some degree for another year (Panel D). This latter case becomes more apparent when we examine shocks to the crop and livestock systems separately. Simulated shocks to the crop sector result in a reduction in food crop sector growth by 12.3 percentage points, causing the sector to decline by 6.4 percent from the base year growth of 5.9 percent (Annex Table A1). In contrast, shocks to the livestock system have only a limited immediate effect on the performance of the sector (Panel D). Furthermore, while the crop sector shock has no further growth effect in the succeeding years on the sector itself, a shock to the livestock system causes growth in the livestock sector to decline by 13.8 and 4.4 percentage points one and two years after the initial shock.

Another remarkable feature of the results is that a shock to the crop sector has a significant immediate and lagged effect on the performance of the livestock sector, which declines by 6.9 percentage points in *t1*. This effect on the livestock sector persists over the medium term, even after the food crop sector has almost fully recovered. Likewise, a shock to the livestock system has a marginally considerable immediate (-1.8 percentage points) and lagged (up to - 0.4 percentage points) growth effect on the crop sector, since livestock is used as a strategic capital input for crop production.

As a result of the contrasting recovery paths of the crop and livestock sectors following the initial separate shocks to the two systems, agriculture exhibits diverging growth trajectories (Panel A). The shock affecting only the crop sector reduces agricultural growth by 8.1 percentage points during the drought year because of the crop sector's size and the magnitude of the immediate impact on crop GDP. However, this effect quickly dissipates the following year. In contrast, the shock affecting only the livestock sector reduces agriculture growth by 1.1 percentage points immediately, reflecting a minor immediate effect on the livestock sector despite its contribution to 31 percent of agriculture's GDP (Aragie and Thurlow, 2021). However, this effect quickly increases to a 5.4 percentage point reduction in agriculture growth, which persists noticeably until *t3*.

In semi-subsistence economies, the agro-processing sector holds strategic significance, serving as a pathway to a diversified and transformed economy. Shocks to the crop and livestock systems reduce the sectors growth trajectory by 2.8 percentage points in the aftermath of the shock, with the growth effects quickly vanishing in the succeeding years. This decline in growth is chiefly attributed to reductions in crop sector output, as processed livestock products constitute only a minor share (approximately 7 percent) of the agro-processing sector.

Figure 3. Impacts of drought on sectoral growth (percentage point deviation from baseline)

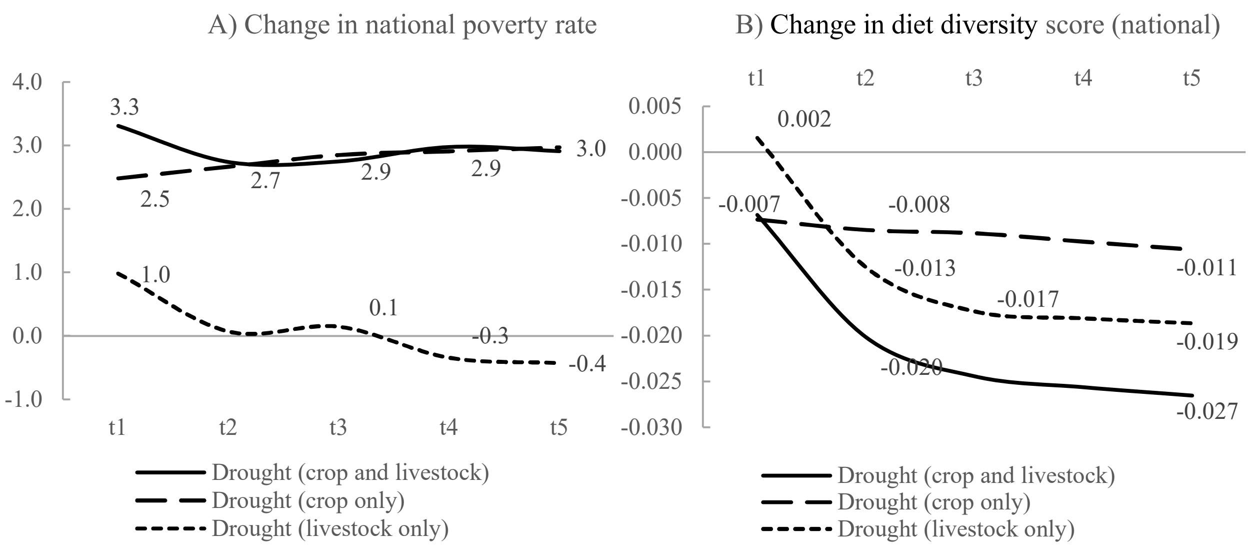


Poverty remains a critical development challenge in most semi-subsistence economies. The crop and livestock systems provide an irreplaceable livelihood basis for the most vulnerable communities. Our results also support this longstanding view. We find that the simulated shocks to the crop and livestock systems cause a persistent and strong increase in poverty than the decline in overall GDP growth since sectors affected directly and strongly by the shocks are the main sources of livelihood and consumption spending for most at the lower end of the income distribution. Specifically, a joint shock to the crop and livestock systems causes the headcount poverty rate to be consistently higher by about 3.0 percentage points (Panel A, Figure 4) than the baseline trajectory (equivalent to over 2.6 million more poor people – see Annex Table A2) compared with the decline in GDP growth of 1.7 percentage points in *t2* and 0.5 percentage points in *t3* (Annex Table A1).

We also observe contrasting effects on poverty when the crop and livestock system shocks are considered separately. First, the effect on poverty is much more pronounced when the shock comes from the crop sector, supporting our prior expectations. Second, drought shock to the livestock sector alone is poverty increasing only during the year of the shock, whereas shock to crops has a persistent effect that stretches throughout the simulation period. The strong and persistent effect of the crop sector shock on poverty is due to its significant impact on overall GDP and the fact that food crops constitute a substantially higher share of consumption spending.

Similarly, persistent rates of poverty are observed in both rural and urban areas (Annex Table A2). However, we noted stronger immediate effects in rural areas, with the burden of poverty shifting to urban households at *t2* and beyond. This discrepancy arises from the differential impact of the drought shock on livestock between rural and urban households. Whereas rural poverty declines from *t2* onwards after an initial increase at *t1*, due to a subsequent decrease in consumer prices despite only a slight decline in food crop production, urban poverty continues to rise. This suggests that the better-off in rural areas and those in urban Ethiopia are more significantly tied to livestock value chains.

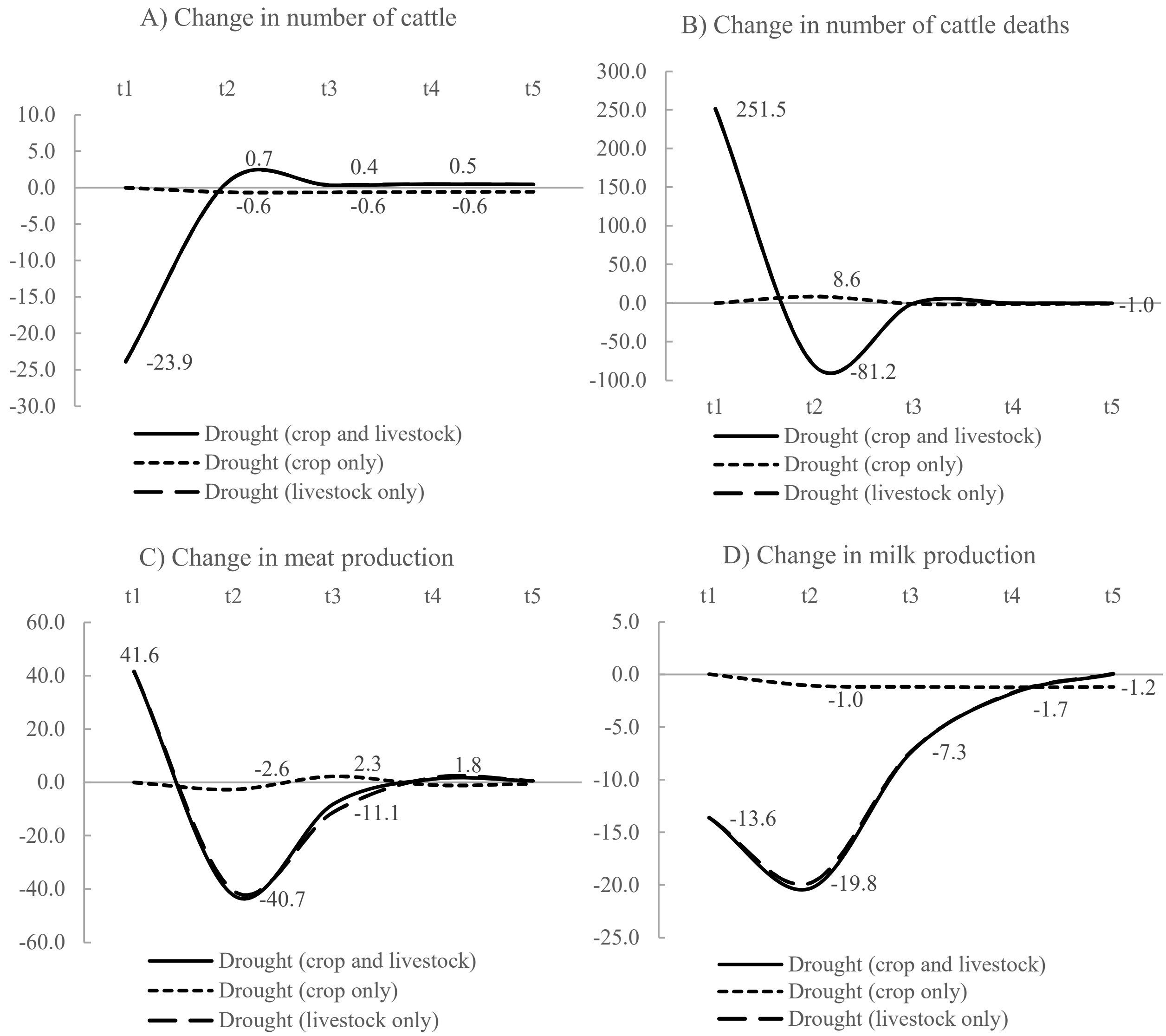
Figure 4. Impacts of drought on household level outcomes (point deviation from baseline)



Results further show that diet diversity deprivation worsens with joint shock to the crop and livestock systems as households face reduced access to food groups to which they have dietary gaps such as milk and meat (Panel B, Figure 4). This is evidenced by the strong and persistent impact the shock to livestock has on the diet diversity score. Drought shock on livestock may have a short-term (*t1*) diet diversifying impact as farmers sell and slaughter more animals to respond to the drought, but it eventually worsens the quality of diets because of reduced sale and slaughtering of animals due to depleting, but recovering stocks (see Panel A, Figure 5). By contrast, the crop sector shock causes minimal impact on diet diversity for several reasons. First, this shock has limited income effect after the year of the shock. Second, cereals constitute a significant share of households' diets, and thus a relative decline in cereals in the consumption basket of a typical household does not significantly harm diet diversity. Overall, the impacts of crop and livestock shocks on diet diversity are more pronounced among urban households compared to rural households (see also Annex Table A3 on the number of people with narrow diets). This is primarily because urban households rely entirely on purchasing food from the market, often at inflated prices during shocks. By contrast, rural households have the ability to stabilize their consumption by relying on their own agricultural production.

In addition to the outcome indicators obtained from the economic system model and discussed above, several interesting results emerge from the animal system model component of the integrated framework adopted in this study. The following are worth exploring in the context of the objective of this paper: changes in the number of cattle, trends in cattle deaths, and changes in meat and milk production. Figure 5 and Annex Tables A4 and A5 report these indicators. Withstanding the 3 percent cattle stock growth at the baseline (see Annex Table A4), changes in cattle size reported for *t1* in Panel A, Figure 5 closely mimics the simulated declines in cattle herd across the drought scenarios. The joint crop and livestock drought scenarios show strong declines in herd size due to extremely high drought-induced deaths (Panel B, Figure 5) and slaughtering before starting to recover from *t2* and onwards. By contrast, the drought on crops has no effect on cattle stock in *t1*, but impacts start to show from *t2*, with a medium-term persistent -0.6 percentage point effect on herd size growth. Panel B further shows the contrasting dynamics of cattle deaths from drought impacts on crops and livestock.

Figure 5. Impacts of drought on selected cattle system outcomes (p. point deviation from baseline)



Meat and milk production are the two livestock systems products tracked in detail in the framework applied in this study. As reported in Panel C, Figure 5, meat production increases by 41.6 percent during the drought year due to forced sales and slaughtering of cattle as the resource constraint intensifies. However, meat production declines during *t2* and *t3* due to the depletion of herd size and subsequent restocking (Annex Table A5). Meanwhile, the shock in the crop sector results in a delayed impact on meat output, primarily due to the delayed effect on animal feed availability. This leads to a decline in yield per head of cattle.

The effect on milk production during the drought year is the reverse of that on meat production (Panel D, Figure 5). We observe a nearly 14 percent decline in milk production at *t1*, which continues along the same trajectory due to reduced yield per head and a lack of milking cows, as the herd size has decreased by over 20 percent. Similar to meat production, the impact of the crop sector drought on milk output remains relatively minimal.

5.2 Impacts of interventions

In this section, we analyze the impact of different interventions in the crop and livestock systems on mitigating the effects of drought and altering the recovery dynamics. We evaluate the effectiveness of these interventions by comparing their outcomes with those observed under the drought shock affecting both crop and livestock systems.

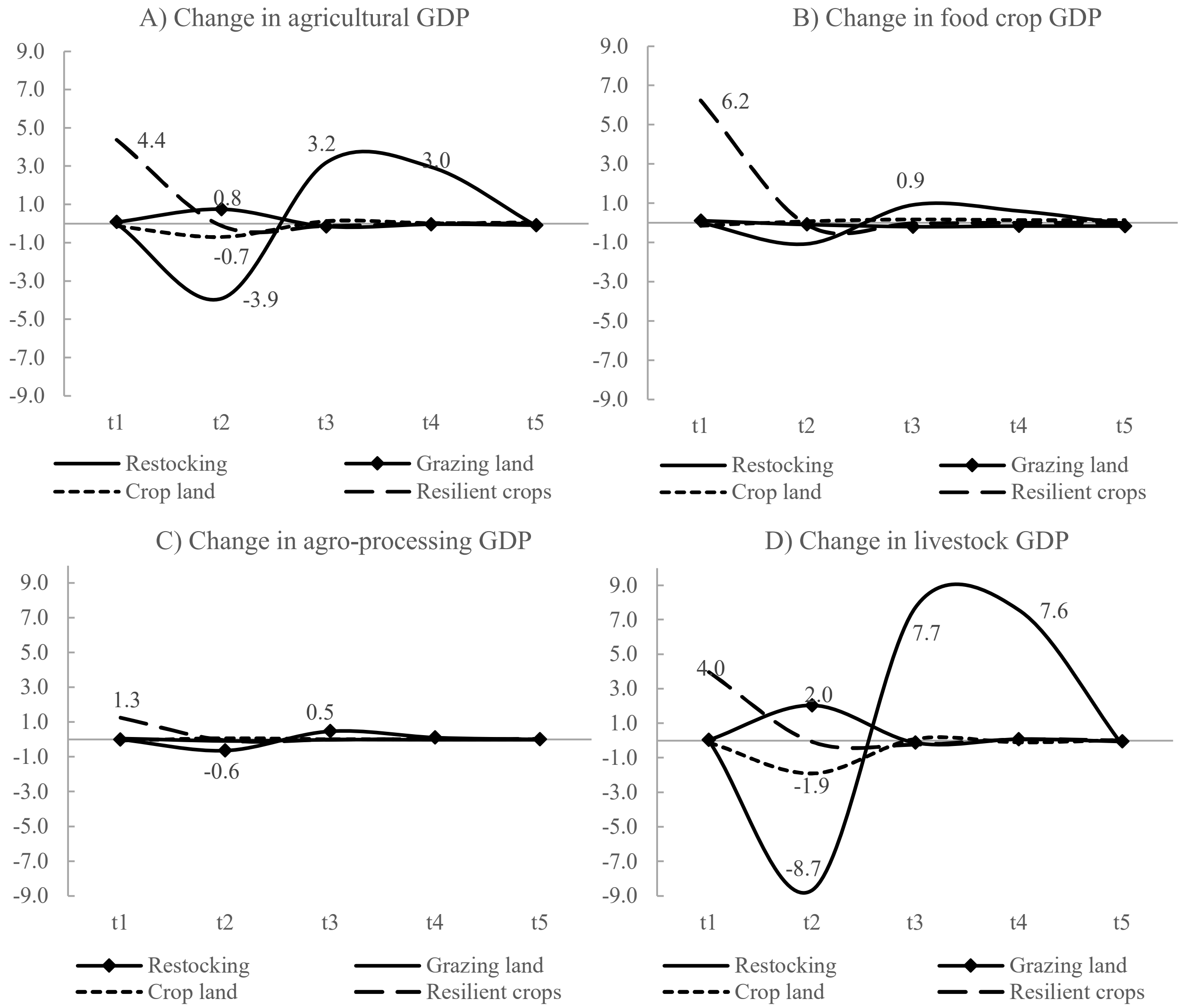
The impacts of interventions centered around livestock systems primarily affect the sector itself (Figure 6). However, the effects present a contrast. Aggressive restocking would initially decrease the growth of meat production and further diminish livestock GDP by 8.7 percentage points in *t2*, before experiencing a recovery in *t3* and beyond. In contrast, grazing land expansion benefits the livestock sector due to rapid but business-as-usual recovery of the herd, while the trend level of meat offtake rate remains in play.

The decline in crop sector GDP is appealing when crop land is converted to grazing land. The further decrease in crop GDP observed when cattle restocking is implemented as a response mechanism is primarily due to the sectoral linkage effect rather than the utilization of livestock as capital in the crop sector. This is evident as the performance of the livestock sector declines further by an additional 8.7 percentage points, indicating that farmers are now able to delay the slaughtering and sale of livestock to re-build their stock, thus reducing the sector's output. However, the agricultural sector as a whole benefits from restocking activity in *t2*, growing 0.8 percentage points faster compared to the outcome under the joint drought scenario.

Meanwhile, converting grazing land to crop land during times of drought further diminishes livestock GDP due to a decrease in both meat and milk yield (Panel C and D, Figure 8), although meat production experiences a brief increase in *t1*. Results also indicate that potential gains in crop GDP are curtailed due to a reduction in traction capital as herd size declines owing to competition for feed. Unlike the grazing land scenario, where agricultural growth accelerates, the sector experiences further deceleration under the crop land scenario.

Among the response options examined, the resilient crop scenario has a sector-indifferent impact, with this impact primarily concentrated in *t1*. Enhanced crop farming practices that reduce the current drought's yield burden by half would improve the sector's performance by 6.2 percentage points in *t1* (Panel B, Figure 6), ultimately resulting in a 4.0 and 4.4 percentage points faster growth in livestock and agriculture GDP, respectively, compared to without the intervention. This improved performance of the agriculture sector aids in the recovery of the agro-processing sector, nearly halving the growth lost in *t1* due to the shock (Panel C, Figure 6).

Figure 6. Impacts of drought on sectoral growth under interventions (percentage point deviation from drought scenario)



The grazing land and crop land expansion scenarios exhibit minute but completely opposite effects on the poverty headcount. Results suggest that grazing land expansion during times of drought may slightly reduce poverty, while crop land expansion at the expense of grazing land would lead to a slight increase. However, the trend reverses in the following year. Crop land expansion is found to be poverty-reducing, particularly in rural areas (see Annex Table A2), as the majority of the rural poor rely on the crop sector for both production and consumption.

Aggressive restocking following drought helps reduce poverty at the national level, although poverty increases in urban areas due to worsening economic performance, as discussed earlier. Rural poverty declines because this helps the crop and livestock sector recover robustly, as evidenced by the bounce back in agriculture growth in *t3* and *t4* (Panel A, Figure 6). Similar to its effect on sectoral GDP, the resilient crop scenario has the strongest impact on poverty. This intervention reduces the poverty rate by 1.4 percentage points (Panel A, Figure 7), lifting around 400 thousand people (see Annex Table A2) — mainly in rural areas—above the poverty line compared to the scenario with the joint drought shock.

Panel B, Figure 4 illustrates that the drought shock significantly deteriorates the diet quality of consumers. Restocking and crop land expansion exacerbate this deterioration by further limiting access to quality and diversified diets, partly by limiting access to animal-source food as the livestock sector declines further (Panel D, Figure 6). On the other hand, expanding land for grazing and enhancing the resilience of the crop sector against weather shocks both improve diets by increasing access to and affordability of food items, including milk, meat, fruits, and vegetables, which are essential for addressing dietary gaps. The resilient crops scenario has the most significant impact on the diet diversity score due to marked improvements in the performance of both the crop and livestock sectors (Figure 6).

Figure 7. Impacts of drought on household level outcomes under interventions (percentage point deviation from drought scenario)

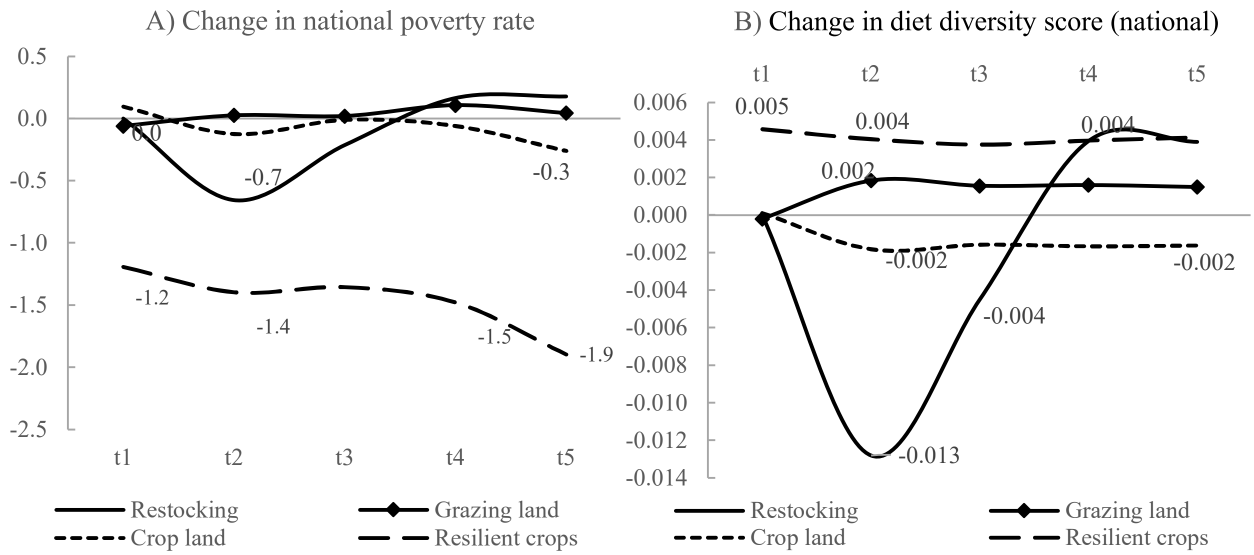
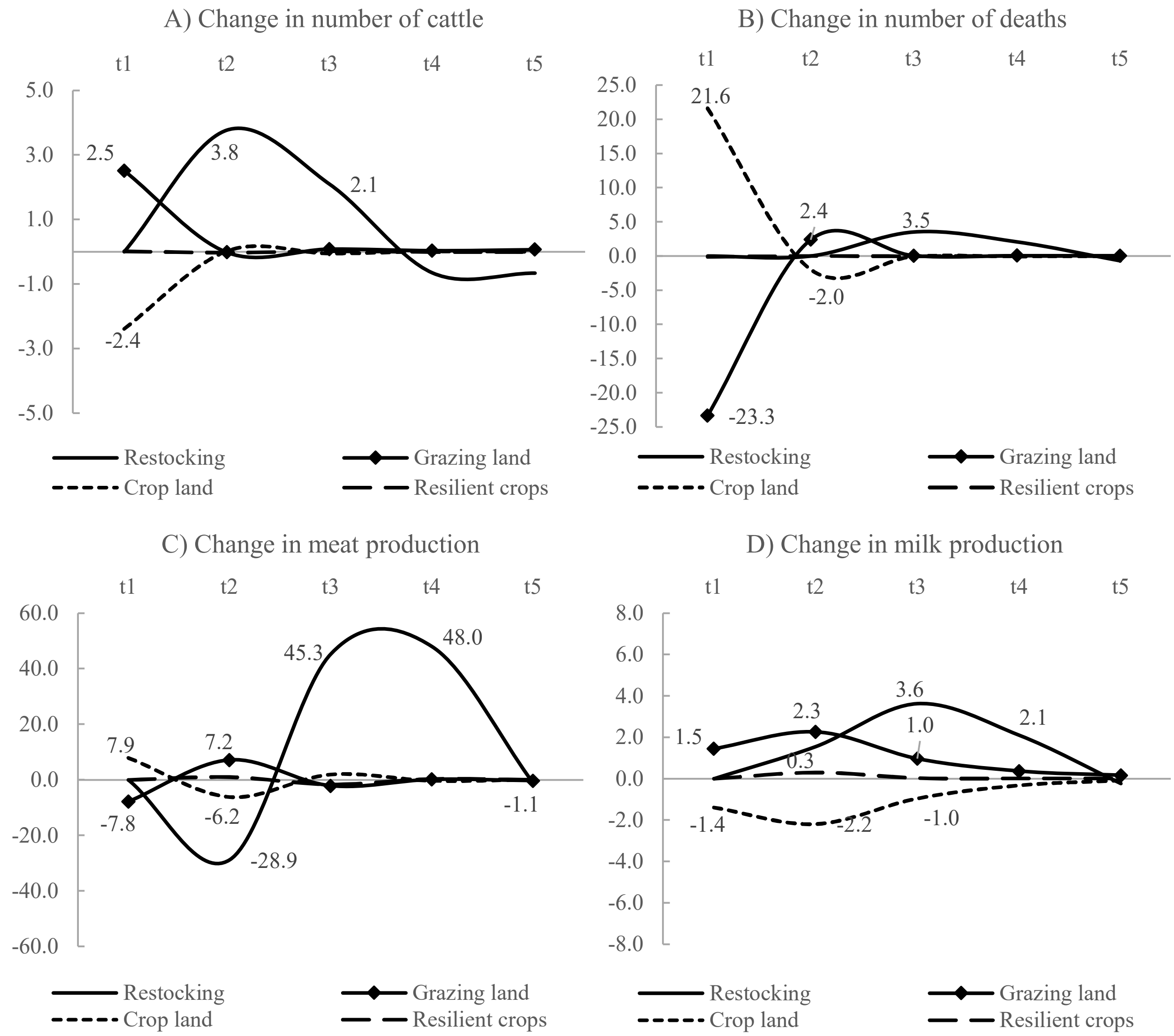


Figure 8 reports the impacts of various interventions on selected cattle system outcomes, expressed in percentage point deviations from the joint drought scenario. The first panel in the figure shows that halving the cattle offtake rate to aggressively restock the herd accelerates the recovery rate by 3.8 and 2.1 percentage points in *t2* and *t3*, respectively, before the stock expansion rate stabilizes. However, this intervention temporarily reduces meat production growth in *t2* by 29 percentage points (Panel C) because of fewer slaughters. Meat production increases again in *t3* and beyond as the stock replenishes and farmers slow down restocking. With the increase in stock, milk production also improves compared to the scenario without this intervention. However, as the cattle stock recovers sufficiently, per capita feed availability becomes constrained, leading to a slight increase in death rates by *t3* (Panel B).

Unlike restocking, which impacts the stock number and its growth rate from *t2* onwards and throughout the simulation period, the grazing and crop land reallocation options only affect the stock in *t1*. However, they have opposite effects on the livestock system. While grazing land expansion aids in maintaining a higher stock, lower death rate, and more milk production at the end of the drought year, crop land expansion leads to opposite but comparable changes in these livestock system outcomes. Meanwhile, bolstering crop sector resilience against drought has a marginally positive impact on these outcomes due to the limited application of modern feeding approaches for cattle rearing.

Figure 8. Impacts of drought on selected cattle system outcomes under interventions (percentage point deviation from drought scenario)



6 CONCLUSION AND POLICY IMPLICATIONS

Mixed crop-livestock systems dominate farming, particularly in sub-Saharan Africa, and serve as crucial sources of livelihood for many people. However, these systems are highly vulnerable to the impacts of climate change, and the interactions between crop and livestock components can exacerbate these effects, potentially leading to irreversible consequences. This study employs a spatially disaggregated linked economy and animal systems model, incorporating environmental and climate change factors into its forage supply function and recognizing animal traction as a capital factor in the crop sector. Consequently, the study offers a unique contribution by modeling the dynamic adjustments of both crop and livestock sectors, along with livestock system outcome indicators. It aims to understand the impacts of a one-time drought on a typical semi-subsistent economy, using Ethiopian as example, when the close interaction between the crop and livestock sectors is properly accounted for. We also explore the contribution of selected crop and livestock system interventions and investigate the differences in the adjustment dynamics of the two systems in response to these interventions.

We find that a joint shock to the crop and livestock sectors produces unique effects on each system. Food crops experience a strong and immediate growth effect that fades quickly, while the livestock sector feels the full impact of the shock a year later, with the effects persisting to some degree. We also find diverging economic and livestock systems adjustment trajectories from separate shocks to the crop or livestock sector. Crop sector shocks reduce food crop sector growth by 12.3 percentage points, causing a decline of 6.4 percentage points from the base year's growth of 5.9 percent. Conversely, livestock sector shocks have limited immediate effects but lead to declines of 13.8 and 4.4 percentage points in growth one and two years later. Notably, the crop sector shock significantly affects the livestock sector performance instantly and in the long term. Similarly, livestock shocks marginally affect crop sector growth, as livestock serves as a vital capital input in crop production.

Simulated shocks to the crop and livestock systems lead to a persistent and significant increase in poverty, outweighing the decline in overall GDP growth. This is because the sectors directly affected by the shocks are primary sources of livelihood and consumption spending for many at the lower end of the income distribution. When considering the shocks separately, contrasting effects on poverty emerge. The impact is more pronounced and enduring when the shock originates from the crop sector, as food crops represent a larger share of consumption spending. Additionally, the deprivation of diet diversity worsens with joint shocks to the crop and livestock systems, as households experience reduced access to essential food groups such as milk and meat. This is evident from the substantial and persistent impact of the livestock shock on diet diversity scores.

Several interesting results also emerge from the animal system module component of the integrated framework adopted in this study. We observe contrasting movements in various cattle system outcome indicators. We specifically observe complete reverse milk and meat production effects during the drought year. Whereas meat production increases by up to 42 percent in the aftermath of the drought due to forced sales and slaughtering, milk output declines by nearly 14 percent, due to a decline in yield per head and lack of milking cows as the herd depletes.

On the other hand, the four intervention options analyzed – restocking, grazing land expansion, crop land expansion, and resilient crops – produce contrasting impacts on various outcomes, with only the resilient crop intervention scenario showing sector-indifferent effects. In summary, the simulation results signal the need for longer-term dynamic analysis and policy planning to address the complex and evolving challenges posed by climate extremes and their impacts on the agricultural sector and the wider economy.

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8 APPENDIX

Table A1. Impacts on overall and sectoral GDP growth

	Total GDP					Agriculture GDP					Food crop GDP					Livestock GDP				
Year/Scenario	t1	t2	t3	t4	t5	t1	t2	t3	t4	t5	t1	t2	t3	t4	t5	t1	t2	t3	t4	t5
Baseline	6.6	6.6	6.7	6.8	6.8	6.5	6.5	6.5	6.6	6.6	5.9	5.9	5.9	5.9	5.8	7.7	7.6	7.7	7.8	7.9
Drought scenarios	*Percentage point deviation from baseline growth*																			
Crop and livestock	-3.6	-1.7	-0.5	0.0	0.0	-9.5	-5.3	-1.4	-0.1	0.0	-14.1	-0.3	0.0	0.1	0.1	-8.2	-13.9	-4.1	-0.5	0.0
Crop only	-3.2	-0.1	0.0	-0.1	-0.1	-8.1	-0.3	0.0	-0.3	-0.2	-12.3	-0.1	0.0	-0.1	-0.1	-6.9	-0.8	-0.2	-0.6	-0.6
Livestock only	-0.3	-1.9	-0.5	0.0	0.0	-1.1	-5.4	-1.6	-0.1	0.0	-1.8	-0.4	-0.1	0.1	0.1	-0.5	-13.8	-4.4	-0.4	0.0
Intervention scenarios	*Percentage point deviation from drought (crop and livestock) scenario*																			
Restocking	0.0	-1.5	1.2	1.0	0.0	0.0	-3.9	3.2	3.0	-0.1	0.0	-1.1	0.9	0.6	0.0	0.0	-8.7	7.7	7.6	-0.3
Grazing land	0.0	0.2	-0.1	0.0	0.0	0.1	0.8	-0.1	0.0	-0.1	0.1	-0.1	-0.2	-0.2	-0.2	0.0	2.0	-0.1	0.1	-0.1
Crop land	0.0	-0.2	0.0	0.0	0.0	-0.1	-0.7	0.1	0.0	0.1	-0.1	0.1	0.2	0.1	0.1	-0.1	-1.9	0.1	-0.1	0.0
Resilient crops	1.7	-0.1	0.0	0.0	0.0	4.4	-0.1	-0.1	0.0	0.0	6.2	-0.1	0.0	0.0	0.0	4.0	-0.1	-0.2	0.1	0.0

Table A2. Impacts on poverty headcount ('000)

	National						Rural						Urban					
	t0	t1	t2	t3	t4	t5	t0	t1	t2	t3	t4	t5	t0	t1	t2	t3	t4	t5
	Number of poor people under the baseline scenario																	
Baseline	23,488	22,723	21,882	20,921	19,849	18,635	20,268	19,397	18,476	17,417	16,241	14,915	3,220	3,326	3,406	3,504	3,608	3,721
Drought scenarios	*Deviation in the number of poor people from baseline scenario*																	
Crop and livestock	-	2,950	2,504	2,578	2,862	2,870	-	2,479	1,852	1,866	2,138	2,174	-	471	652	712	724	696
Crop only	-	2,213	2,436	2,672	2,795	2,928	-	1,753	1,908	2,132	2,255	2,403	-	460	528	540	540	525
Livestock only	-	876	63	136	(330)	(422)	-	907	(107)	(72)	(518)	(576)	-	(32)	170	208	188	154
Intervention scenarios	*Deviation in the number of poor people from drought (crop and livestock) scenario*																	
Restocking	-	-	(600)	(200)	158	174	-	-	(844)	(292)	219	243	-	-	244	91	(61)	(68)
Grazing land	-	(53)	24	19	104	44	-	(55)	37	28	107	40	-	2	(13)	(9)	(3)	4
Crop land	-	85	(114)	(10)	(58)	(257)	-	81	(127)	(30)	(63)	(260)	-	3	13	20	5	3
Resilient crops	-	(1,063)	(1,277)	(1,270)	(1,421)	(1,869)	-	(785)	(1,019)	(993)	(1,123)	(1,580)	-	(279)	(257)	(278)	(298)	(289)

Table A3. Impacts on number of people with narrow diets (‘000)

	National						Rural						Urban					
	t0	t1	t2	t3	t4	t5	t0	t1	t2	t3	t4	t5	t0	t1	t2	t3	t4	t5
	Number of people with narrow diets under the baseline scenario																	
Baseline	52,661	53,395	54,132	54,842	55,532	56,194	44,010	44,344	44,659	44,935	45,175	45,372	8,651	9,051	9,474	9,907	10,357	10,822
Drought scenarios	*Deviation in the number of people with narrow diets from baseline scenario*																	
Crop and livestock	-	610	1,843	2,291	2,464	2,615	-	501	1,389	1,729	1,872	1,991	-	109	454	562	593	625
Crop only	-	655	775	828	937	1,047	-	469	557	605	688	771	-	186	218	223	249	275
Livestock only	-	(138)	1,148	1,627	1,741	1,839	-	(20)	887	1,239	1,338	1,417	-	(118)	261	388	403	422
Intervention scenarios	*Deviation in the number of people with narrow diets from drought (crop and livestock) scenario*																	
Restocking	-	0	1,171	420	(380)	(385)	-	-	731	243	(271)	(278)	-	0	440	178	(109)	(107)
Grazing land	-	18	(169)	(146)	(154)	(148)	-	6	(122)	(112)	(120)	(117)	-	11	(47)	(34)	(35)	(31)
Crop land	-	(10)	166	148	160	160	-	(2)	120	113	122	123	-	(8)	47	35	38	36
Resilient crops	-	(408)	(370)	(352)	(382)	(409)	-	(283)	(265)	(258)	(280)	(299)	-	(125)	(104)	(94)	(102)	(110)

Table A4. Impacts on cattle stock and number of deaths (‘000)

	Change in number of cattle						Change in number of deaths					
	t0	t1	t2	t3	t4	t5	t0	t1	t2	t3	t4	t5
	Number of cattle and cattle deaths under the baseline scenario											
Baseline	60585.2	62569.4	64608.4	66629.4	68707.3	70831.1	4,595	4,786	4,991	5,184	5,383	5,586
Drought scenarios	*Deviation in number of cattle and cattle deaths from baseline scenario*											
Crop and livestock	-	(14469)	(14573)	(14856)	(15062)	(15286)	-	11559	(1213)	(1269)	(1325)	(1383)
Crop only	-	(3)	(392)	(815)	(1226)	(1646)	-	1	412	380	339	295
Livestock only	-	(14463)	(14585)	(14847)	(15054)	(15280)	-	11555	(1213)	(1270)	(1324)	(1381)
Intervention scenarios	*Deviation in number of cattle and cattle deaths from drought (crop and livestock) scenario*											
Restocking	-	(0)	1,812	2,963	2,714	2,439	-	0	(0)	133	222	200
Grazing land	-	1,521	1,573	1,669	1,746	1,844	-	(1,072)	118	124	132	139
Crop land	-	(1,448)	(1,497)	(1,575)	(1,626)	(1,683)	-	993	(112)	(118)	(124)	(129)
Resilient crops	-	8	(5)	3	1	(2)	-	(5)	1	(0)	1	1

Table A5. Impacts on meat and milk production ('000 tons)

	Change in meat production						Change in milk production					
	t0	t1	t2	t3	t4	t5	t0	t1	t2	t3	t4	t5
	Meat and milk production under the baseline scenario											
Baseline	396,130	410,498	420,418	434,077	447,224	460,914	3,299,074	3,578,169	3,884,172	4,213,027	4,575,757	4,979,650
Drought scenarios	*Deviation in meat and milk production from baseline scenario*											
Crop and livestock	-	165,023	(75,097)	(105,403)	(104,480)	(105,648)	-	(448,224)	(1,122,383)	(1,421,101)	(1,593,299)	(1,733,043)
Crop only	-	93	(10,713)	(1,667)	(5,951)	(8,353)	-	991	(36,376)	(84,026)	(141,329)	(205,799)
Livestock only	-	164,883	(65,202)	(106,913)	(104,266)	(105,303)	-	(448,163)	(1,106,180)	(1,402,651)	(1,572,169)	(1,708,575)
Intervention scenarios	*Deviation in meat and milk production from drought (crop and livestock) scenario*											
Restocking	-	4	(166,049)	(76,826)	40,788	38,243	-	-	48,828	151,294	223,597	236,124
Grazing land	-	(30,822)	20,576	11,768	12,915	12,273	-	48,020	114,460	143,811	164,642	184,610
Crop land	-	31,234	(18,805)	(11,676)	(13,262)	(13,546)	-	(45,781)	(107,913)	(134,344)	(151,977)	(167,650)
Resilient crops	-	(184)	5,490	(628)	300	348	-	79	9,544	10,545	11,749	13,341

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