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Access to markets, weather risk, and livestock production decisions

Evidence from Ethiopia

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ABSTRACT

Despite several studies showing the effect of access to markets and weather conditions on crop production, we know quite little on whether and how livestock production systems respond to variation in weather risk and access to markets. In this paper, we study whether and how livestock production responds to access to markets and varying weather risk. We also explore whether such responses vary across livelihood zones and livestock production systems. We study these research questions using information on the livestock production, ownership, and marketing decisions of households in Ethiopia. We find that households living close to markets are more likely to engage in market-oriented livestock production and use modern livestock inputs. We also find that households exposed to more unpredictable weather are less likely to engage in livestock production for markets. Rather, they are more likely to engage in livestock production for precautionary savings and insurance. Furthermore, greater rainfall uncertainty influences livestock portfolio allocation towards those types of livestock which can be easily liquidated, while also discouraging investment in modern livestock inputs. However, these responses and patterns vary across livelihood zones and production systems – most of these stylized responses and impacts are more pronounced in the arid and semi-arid lands of Ethiopia, where livestock herding remains a dominant source of livelihood. Those households relying only on livestock production seem more sensitive and responsive to weather risk and weather shocks. The heterogeneity in responses to and impacts of weather risk among farming systems and livelihoods highlights the need for more tailored livestock sector policies and interventions.

JEL Codes: D12, D13, D81, Q12, Q13.

Keywords: Livestock production, weather risk, markets, portfolio allocation, marketing.

1. INTRODUCTION

Does household livestock production respond to access to markets and weather conditions? Despite several studies showing that crop production responds to weather conditions (e.g., Rosenzweig and Binswanger 1993; Dercon 1996; Jalan and Ravallion 2001; Howden et al. 2007; Mitter et al. 2015; Amare et al. 2018; Jagnani et al. 2018)[1] and access to markets (e.g., de Janvry et al. 1991; Fafchamps 1992: Zeller et al. 1998; Van Dusen and Taylor 2005), there exists scant empirical evidence on whether and how households' livestock production decisions respond to varying weather risk and access to markets. Understanding these responses and adjustments in livestock production and marketing decisions is crucial for prioritizing livestock-related investments and designing risk mitigating strategies for those relying on livestock, e.g., livestock insurance programs.

It is widely believed that access to rural markets can improve the efficiency and productivity of smallholders, including livestock holders (World Bank 2010; 2017). Indeed, lack of access to markets is commonly invoked as a key explanation for smallholders' low productivity and existing factor misallocations in the developing world (e.g., Banerjee and Duflo 2005; Restuccia and Santaeulalia-Llopis 2017). However, this well-established theoretical wisdom assumes that, among other things, crop and livestock production systems respond strongly to access to markets. However, this is an empirical question that is expected to vary across livelihoods and production systems, and, therefore, remains poorly understood in the context of livestock production.

[1] These studies show that farmers' crop choice and, hence, production decisions respond to weather variability and rainfall shocks (e.g., Dercon et al. 1996; Amare et al. 2018). Rosenzweig and Binswanger (1993) show that farmers exposed to substantial rainfall uncertainty tend invest on asset portfolio that is more resilient to rainfall shocks.

Understanding the interaction between markets and livestock production is particularly crucial to justify and prioritize the investments of governments and donors on livestock production and market infrastructure.

Similarly, we know quite little on whether and how livestock production responds to weather risk and weather conditions. There is also limited evidence on whether potential responses in livestock production vary across alternative livelihood and production systems. For instance, livestock production remains the largest source of livelihood in the arid and semi-arid lands (ASAL) of eastern Africa. These regions also are among the most vulnerable to weather shocks (e.g., Thornton et al. 2002; Thornton et al. 2006). In the non-ASAL regions of east Africa, where mixed farming remains the dominant livelihood strategy, livestock production is not the dominant source of income and employment. One can intuitively expect that households' livestock production, marketing, and consumption decisions evolve differently across these livelihood zones, and so will the response of these households to weather shocks.

In this paper, we study whether and how livestock production responds to access to markets and weather risk. We also explore whether such responses vary across livelihood and production systems. We study these research questions using three (longitudinal) waves of the Living Standard Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) data for Ethiopia. These nationally representative data cover a large sample of households throughout the country with varying livelihood and production systems. The LSMS-ISA data include the spatial coordinates of households and enumeration areas, enabling the merging of these data on livestock production, ownership, and marketing decisions with remote sensing data, including distance to markets and rainfall data. We employ Euclidean distance to the nearest permanent market to measure the access of a household to markets and define our measure of weather risk as the coefficient of variation of local rainfall over the last 10 years. We measure and characterize livestock production decisions in terms of: (a) orientation of production (self-reported main purpose of livestock ownership), (b) livestock portfolio allocation across alternative livestock types, and (c) modern livestock input use. Similarly, we characterize households' marketing decisions in terms of market participation and selling of animal source foods (ASF). In the interest of uncovering potential heterogeneities in the response of livestock production and marketing decisions across livelihood zones, we separately estimate responses for the ASAL and non-ASAL regions.

Investigating the potential of markets to shape livestock production and marketing patterns as well as the response of these decisions to weather conditions in the context of Ethiopia is appealing for several reasons. Despite abundant livestock resource, Ethiopia's value of livestock production and consumption remains far below production potentials.[2] This low production and productivity has limited the contribution of the livestock sector to the overall GDP of Ethiopia (Bachewe et al. 2017). Poor access to markets and recurring weather shocks are two central explanations commonly invoked to justify such low performance of the livestock sector (Negassa and Jabbar 2008; Duncan et al. 2013; Gebremedhin et al. 2017).[3] Smallholders and pastoralists in Ethiopia lack access to markets for livestock inputs and livestock products, and only a small number of smallholder farmers and pastoralists in Ethiopia participate in livestock markets (e.g., Negassa et al. 2008). Indeed, the Ethiopian Livestock Master Plan (LMP) proposes that improving market linkages and the market orientation of livestock-keeping households in Ethiopia can meaningfully improve the welfare of livestock herders and the sector's contribution to the Ethiopian economy (Shapiro et al. 2015). Furthermore, livestock production in Ethiopia relies heavily on rainfall and, hence, is subject to the vagaries of nature. Such uninsured production risk has been shown to reduce investments in

[2] For instance, while Ethiopia's livestock population remains the largest in Africa, annual value of milk production is estimated to be around 1.1 million USD for the year 2011, which is below neighboring Kenya's production that owns only 34 percent of Ethiopia's livestock population (FAOSTAT 2011).

[3] Other constraints and explanations include limited availability and low adoption of improved livestock inputs and breeds (e.g., Duncan et al. 2013; Makoni et al. 2013).

productivity-enhancing investments by smallholder crop producers in many contexts, even trapping them in poverty (e.g., Dercon 1996; Zimmerman and Carter 2003; Carter and Barrett 2006; Dercon and Christiaensen 2011). Understanding the behavioral responses of livestock producers to this uninsured weather risk remains crucial as some of these behavioral adjustments could discourage productive livestock investments and, hence, perpetuate poverty traps (Jalan and Ravallion 2001; Lybbert et al. 2004). However, rigorous studies exploring the response of livestock production and consumption to market access and weather risk remain scant.

We find that smallholders' livestock production and marketing decisions are responsive to markets and weather conditions. Livestock herders located nearby markets are more likely to orientate their livestock production towards markets, both in terms of sale of live animals and livestock products. Increased access to markets is also related to increases in modern livestock input use. Although we cannot distinguish if the relationship between the proximity of markets and modern livestock use is supply or demand driven, it is likely to have implications on the productivity of herds. These findings are particularly relevant for livestock producers and pastoralists in east Africa, which historically have had limited access to these critically important input markets (e.g., Barrett et al. 2006; Negassa and Jabbar 2008).

We also find that livestock production significantly responds to weather risk. We show that those households living in variable and unpredictable weather conditions are less likely to engage in livestock production for markets. Instead, they are more likely to engage in livestock production for precautionary savings and insurance purposes. Rainfall uncertainty influences livestock portfolio allocation as well as investment in modern livestock inputs. Those households exposed to more unpredictable rainfall are less likely to invest in large ruminants and in modern livestock inputs, but are more likely to invest in small ruminants. This implies that livestock producers factor in the unpredictability of their production environment when making decisions about which type and how many livestock assets to hold, depending on various production motives.

However, these responses and patterns vary across livelihood zones – most of these stylized responses and impacts are only visible and significant in the ASAL regions of Ethiopia, where livestock herding remains a dominant source of livelihood. Intuitively, this evidence provides two key insights. First, the heterogeneity in responses to the impacts of weather risks among farming systems and livelihoods highlights the need for more tailored livestock sector policies and interventions.[4] Second, as commonly argued and reflected in the extreme poverty rates in ASAL regions, households relying on livestock production as a main source of livelihood are probably more susceptible to weather risk than are those households relying on a more diversified livelihood portfolio. In the absence of well-functioning insurance markets to deal with covariance production risk, these responses can effectively limit households' livestock investments. These results reinforce recent attempts to mitigate livestock herders' production risks in the ASAL regions of east Africa. Index-based livestock insurance is one of these instruments, providing a viable means to reduce the consequences of weather shocks (Chantarat et al. 2013; Jensen and Barrett 2016; Jensen et al. 2017).

2. DATA AND CONTEXT

2.1. Data Source

We employ the Living Standards Measurement Study Integrated Surveys on Agriculture (LSMS-ISA) data for Ethiopia, a collaborative project between the Central Statistics Agency of Ethiopia

[4] Consistent with this argument Pica-Ciamarra et al. (2015) document that livestock production and ownership decisions vary across countries and farming systems, highlighting the need for more tailored and customized livestock policies.

(CSA) and the World Bank. Despite some limitations, the LSMS-ISA provide ‘‘relatively detailed’’ information on livestock production and consumption decisions of households.[5] The Ethiopian LSMS-ISA data are longitudinal datasets collected every two years, covering a wide range of topics, including a detailed module on livestock production and consumption decisions of households.

Three rounds of the LSMS-ISA data have been collected from households in Ethiopia, with the first round collected in 2011/12 while the second and third coming in 2013/14 and 2015/16, respectively. The first round covers only rural and small towns, and, hence, is only representative of rural Ethiopia, while the second and third rounds include urban areas and, hence, are nationally representative. The first wave sampled about 4,000 households while the second and third rounds were expanded to include about 1,500 urban households. The sampling strategy involves two-stage probability sampling, with the first stage of sampling involving selection of enumeration areas using simple random sampling while the second stage involves random selection of households from each enumeration area.[6] Most of those households from rural and some households in urban areas are engaged in farming or livestock activities.

Besides the longitudinal nature of the data, the LSMS-ISA data for Ethiopia provide additional geospatial data, including measures of Euclidian distance to the nearest permanent market. The LSMS-ISA team constructed these spatial data using information on the spatial coordinates of the residence of the sample households and enumeration areas (villages). These coordinates were collected during the household survey fieldwork. The Euclidean distance to markets is constructed at household level using the spatial coordinates of a household’s residence and that of the nearest permanent market.[7] We employ the Euclidian distance to the nearest permanent market as an indicator for access to markets. Distance to markets represent one of the key constraints to accessing markets (Renkow et al. 2004; Melesse and Cecchi 2017). However, this measure has some limitations as the Euclidian distance measure fails to account for terrain and associated infrastructural differences. Households have limited scope to influence their distance to markets, except through migration decisions. Migration appears to be generally low in our sample as reflected by the low level of sample attrition. Hence, Euclidean distance to nearest market may be considered as largely exogenous to households’ livestock production decisions, especially in contexts where rural mobility is not very common. The low attrition rate (about 5 percent) in our sample suggests that household-level mobility and migration may not be widespread, although individual-level migration is expected to be higher.[8]

Using the GPS coordinates of enumeration areas, we further merge these longitudinal data with time-series rainfall data. As we are interested in understanding the implication of long-term weather conditions and weather risk, we extract long time-series of rainfall data from the National Aeronautics and Space Administration (NASA).[9] Using this geographic information, we are able to construct long-term enumeration area level rainfall data, from which we construct our measure of weather risk, the coefficient of variation of rainfall computed over ten years prior to each survey period. Given the vagaries of precipitation, rainfall variability is expected behave exogenously.

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[5] Most available household level data sources suffer from some limitations for studying livestock production and consumption decisions (Pica-Ciamarra et al. 2015). Existing longitudinal datasets are not sufficiently detailed to understand the interaction among markets, weather and livestock production decisions.

[6] Documentation about the sampling design and features can be found at: http://siteresources.worldbank.org/INTLSMS/Resources/3358986-1233781970982/5800988-1367841456879/9170025-1427144247562/ESS2_Basic_Information_Document.pdf

[7] The market location information is from the Famine Early Warning System Network (FEWS NET) (https://fews.net/markets-and-trade).

[8] Attrition rates are found at: http://siteresources.worldbank.org/INTLSMS/Resources/3358986-1233781970982/5800988-1367841456879/9170025-1427144247562/ESS2_Basic_Information_Document.pdf

[9] See https://power.larc.nasa.gov/common/php/POWER_AboutAgroclimatology.php

2.2. Descriptive Statistics

The LSMS-ISA surveys for Ethiopia elicit detailed demographic and socioeconomic characteristics of households along with information on various elements of household production and consumption decisions. Table 2.1 provides summary statistics associated with household socioeconomic characteristics, pooled across the three survey rounds.

Table 2.1: Descriptive statistics of analytical variables

Variables	Observations	Mean	Standard deviation
Male household head, 0/1	12,951	0.71	0.45
Age of household head, years	12,933	44.8	15.5
Average age of household members, years	12,945	26.2	12.44
Literate household head, 0/1	12,953	0.48	0.50
Household size, number	12,953	5.2	2.58
Livestock ownership (TLU)[10]	13,014	3.3	9.35
Own livestock, 0/1	12,971	0.61	0.49
Farm size, ha	13,011	1.22	23.22
Has access to formal credit, 0/1	12,991	0.08	0.27
Has access to microfinance, 0/1	13,014	0.36	0.48
Household (at least one member) has phone	13,014	0.48	0.49
Euclidian distance to nearest permanent market, km	14,152	59.4	49.86
Euclidian distance to nearest permanent market, km: ASAL	5,797	48.2	48.49
Euclidian distance to nearest permanent market, km: non-ASAL	8,355	65.5	51.74
Long-term average annual rainfall, mm: ASAL	5,193	649	114.5
Long-term average annual rainfall, mm: non-ASAL	7,750	879	134.3
Rainfall coefficient of variation: ASAL	5,193	0.12	0.04
Rainfall coefficient of variation: non-ASAL	7,750	0.11	0.04
Experienced rainfall shock, 0/1	12,992	0.18	0.38
Experienced rainfall shock, 0/1: ASAL	5,193	0.22	0.41
Experienced rainfall shock, 0/1: non-ASAL	7,750	0.15	0.35

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: Summary statistics for sample households pooled over the three panels of data collection.
TLU = tropical livestock unit, ASAL = arid and semi-arid lands.

One of our key variables of interest is access to permanent markets, proxied by the Euclidean distance in km to the nearest permanent market. On average households are located about 59 km far away from the nearest major market, with slight variation across the ASAL and non-ASAL regions.[11] We classify areas into ASAL and non-ASAL regions based on agro-ecological zones.[12] This implies that most households have limited access to markets or will have to incur substantial transport and transaction costs to access major markets. Theoretically, positive marketable surplus for livestock products is commonly linked with shorter distance to markets (Holloway et al. 2008). Our measure of weather risk, measured by the coefficient of variation in annual rainfall, appears to be of comparable magnitude across the ASAL and non-ASAL regions. This is despite the significant differences in rainfall patterns and long-term average rainfall across these regions.

[10] Tropical Livestock Unit (TLU) values are computed using the following arithmetic formula: TLU = camels + (0.7*cattle) + (0.8*horses) + (0.5*donkeys) + (0.5*mules) + (0.1*sheep) + (0.1*goats) + (0.01*chicken).

[11] The average distance to markets is relatively high mainly because we are considering major and permanent markets and not village markets.

[12] Agro-ecological zones characterized as tropical arid or tropical semiarid areas are classified as ASAL, while remaining zones are categorized as non-ASAL.

2.1. Livestock Production Orientation

The LSMS-ISA surveys for Ethiopia devote one module for collecting information on livestock ownership, production, and consumption outcomes. Despite some inconsistencies across rounds, this livestock module provides reasonably exhaustive information on livestock ownership, main purpose for livestock ownership, livestock input use, and production and consumption of animal source foods (ASF). However, the structure and organization of the livestock module and data vary across topics and years. For instance, production orientation and purpose of livestock production is elicited for each livestock type only in the last round. Similarly, production, marketing, and consumption decisions for animal source foods (e.g., milk, butter, cheese and eggs) are surveyed for each product. Because of these differences between survey rounds, the sample size in our data vary across these topical items.

Table 2.2 provides summary statistics extracted from the Ethiopia LSMS-ISA livestock modules. In the interest of uncovering potential differences across production systems and livelihoods, we present these figures disaggregated across two groups, one for households in the ASAL regions, which commonly practice pastoralism and rely heavily on livestock production, and one for households from the non-ASAL regions of Ethiopia where households are more likely to practice mixed farming systems.

Livestock play manifold roles in the livelihoods of rural households. Livestock are commonly used for physical production of meat, milk, manure, and draught power, while also serving as a major source of income, insurance, and social status display (Rosenzweig and Wolpin 1993; Bennison et al. 1997; Moll 2005; Moll et al. 2007; Pica-Ciamarra et al. 2015). Moll (2005) provides a theoretical framework for the cost-benefit analysis of livestock production systems that considers the above roles and purposes of livestock ownership and production. Most importantly, Moll (2005) highlights that some of the above purposes can be assigned market prices, while others only generate values and preferences to livestock keepers, leading to the important distinction between marketed and non-marketed services. A comprehensive cost-benefit analysis of livestock production systems should consider both marketed and non-marketed services and benefits (Moll 2005). Besides acknowledging the multiple purposes of livestock, identifying and characterizing these roles of livestock in the household economy is crucial to improve the productivity of livestock producers (Pica-Ciamarra et al. 2015).

Households' livestock production orientation and objectives are commonly elicited using stated preference surveys or preference scoring exercises (e.g., Bennison et al. 1997), and the LSMS-ISA for Ethiopia follows similar approach. The livestock module elicits households' main (most important) purpose for keeping each specific type of livestock (e.g., oxen, cows, sheep, and goats), offering an exhaustive list of purposes for livestock production. The design of this module and, hence, the list of production objectives considered is informed by previous research and local practices (Pica-Ciamarra et al. 2015). In the Ethiopian LSMS-ISA, the list of purposes include: (1) sale of live animals, (2) sale of animal products, (3) food for family, (4) precautionary savings and insurance, (5) signaling social status, (6) farming (crop agriculture), and (7) other purposes (e.g., transport). Among these seven purposes, households are asked to select the most relevant to their purpose of livestock keeping (production), and this is elicited for each type livestock they own. The list of production objectives is comprehensive and covers most of the production purposes identified in the literature (Bennison et al. 1997; Moll 2005; Moll et al. 2007; Pica-Ciamarra et al. 2015). The first seven rows of Table 2.2 describe the main purpose of livestock ownership and, hence, the livestock production orientation of the survey households.

Because of the manifold purposes and roles of livestock, these categories are not completely exclusive of each other. However, capturing the most relevant purpose can provide useful information about households' livestock production priorities and orientation. As we discuss in

Section 3.1, we assume that farmers enjoy and maximize utility associated with each type of livestock service. Thus, households are assumed to engage in a specific livestock production strategy that gives them the highest utility.

Table 2.2: Descriptive statistics of livestock ownership, production orientation, and marketing decisions

Variables	All	ASAL	Non-ASAL
Main purpose of livestock ownership			
Market: Sale of live animals, %	25.0	25.1	25.0
Market: Sale livestock products, %	13.1	12.4	13.6
Savings and insurance, %	11.8	9.9	13.2
Crop agriculture, %	12.3	9.4	14.4
Non-market: Food for family, %	6.2	5.6	6.7
Non-market: Social status, %	9.1	10.0	8.5
Non-market: Transport and related others, %	22.4	27.7	18.6
Observations	*16,894*	*7,096*	*9,798*
Livestock ownership (numbers)			
Cattle	3.99	3.89	4.06
Small ruminants	4.52	7.02	2.97
Camels	0.18	0.45	0.02
Poultry	3.75	3.84	3.69
Equines[13]	0.61	0.67	0.58
Livestock portfolio allocation (% TLU)			
Share in cattle, %	66	57	71
Share in small ruminants, %	18	23	14
Share in camels, %	2	5	0
Share in poultry, %	7	7	7
Share in equines, %	8	9	8
Livestock inputs used			
Exotic livestock, %	2.4	3.1	1.9
Share of exotic livestock, %	2.1	2.7	1.7
Observations	*18,377*	*7,448*	*10,924*
Hybrid livestock, %	2.6	3.1	2.3
Share of hybrid livestock, %	2.0	2.6	1.7
Observations	*11,604*	*4,642*	*6,957*
Livestock products and marketing			
Produced animal-source foods (ASF): milk, %	50.2	55.3	47.1
Sold ASF: milk, %	13.9	23.7	7.1
Share of ASF sold: milk, %	54.7	55.3	53.4
Produced ASF: butter, %	36.8	29.1	41.3
Sold ASF: butter, %	52.7	43.5	56.6
Share of ASF sold: butter, %	57.0	56.9	57.1

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: Summary statistics for sample households pooled over the three panels of data collection.
ASAL = arid and semi-arid lands; TLU = tropical livestock unit; ASF = animal-source food.

[13] Equines include horses, mules, and donkeys.

In order to better understand the motives of livestock keeping and production objectives, we classify the full list of purposes according to common and important features. First, following Moll (2005) we start by classifying production motives into market-related and “other” motives by assessing whether a specific production motive immediately involves market prices and market interactions. Based on this definition, the first two categories—sale of animals and sale of livestock products—are market-oriented production goals, while the remaining purposes can be categorized as “other” motives.

Second, to test additional hypotheses related to distinct non-market or other motives that are of particular interest to this research, we maintain insurance and farming-oriented livestock production as two separate production objectives. We particularly aim to examine precautionary savings and insurance motives of households, a major motive and objective of livestock production in some African contexts where formal insurance markets are missing. Precautionary savings and insurance motives hold considerable implications for actions aimed at improving the lives of livestock keepers (Bennison et al. 1997; Moll 2005). For this purpose, we generate a “non-market” related purpose for those households producing livestock for food, signaling social status, and other related purposes, as these are mostly driven by non-market related motives and, hence, may not directly involve market prices (e.g., Moll 2005). This classification, which serves our main analysis, reclassifies the original seven categories into four categories: (i) market-related, (ii) non-market related, (iii) precautionary savings and insurance, and (iv) crop agriculture. We note that, although these classifications facilitate interpretation of our results, they are innocuous in driving our main findings. Our robustness exercises revisit the main analysis using a binary classification of market-related versus “other” motives as well as using the seven unclassified categories listed in Table 2.2.

Overall, about 38 percent of livestock ownership is market oriented, with the major purposes related to sale of live animals and animal source foods. Another sizeable share of households (12 percent) report keeping livestock chiefly for precautionary savings and self-insurance against shocks, while a comparable share is meant for farming (crop agriculture). Such use of livestock assets for precautionary and self-insurance purposes has been observed among livestock producers in Ethiopia and beyond (e.g., McPeak 2006; Mogues 2011). A reasonably large share of households report non-market related production orientations, including livestock production for food, social status, and other related motives. Interestingly, the distribution of production orientation remains comparable across both livelihood zones, except for small intuitive differences. For instance, as production in the non-ASAL regions involve mixed farming, households in these regions are more likely to keep and use livestock for farming purposes.

One of our hypotheses explores the distribution of livestock herders’ production orientations across households with different access to markets and varying weather conditions. We hypothesize that livestock producers adjust herd composition in response to market access and weather conditions. Specifically, we expect that those households with greater access to markets are more likely to engage in market-oriented livestock production, while those households in remote areas are expected to more frequently have other motives and purposes of production. Similarly, we expect that those households experiencing unpredictable weather conditions are more likely to keep livestock for precautionary savings and self-insurance motives. Using the production orientation and stated motives given in Table 2.2, we can empirically test these joint hypotheses on the relationships among livestock production, markets, and weather conditions.

The middle rows of Table 2.2 provide information on households’ livestock ownership (for each type), for both the ASAL and the non-ASAL regions of Ethiopia. We provide evidence on the distribution of livestock ownership using the raw number of livestock owned as well as using the share of Tropical Livestock Units (TLU) allocated among the five livestock groups. We have five categories of livestock – cattle, small ruminants (sheep and goats), camels, poultry, and equines. In the full sample, 66 percent of livestock assets are allocated and invested in cattle, with the smallest share allocated to camels. The distribution of livestock ownership as well as portfolio allocation seem comparable across the ASAL and the non-ASAL regions, except for some livestock groups. For instance, small ruminants appear to be more dominant in the ASAL regions, while cattle are relatively more prevalent in the non-ASAL regions. One of our hypotheses explores whether households' livestock ownership and portfolio allocation responds to weather conditions and access to markets. We expect that households adjust their livestock ownership, type of livestock owned, and investment depending on their access to markets and weather conditions. There are two theoretical justifications and foundations for this hypothesis. First. some types of livestock might be more resilient to weather shocks than others. Second, some types of livestock can be liquidated more easily than others. For instance, small ruminants are expected be to relatively more liquid than large ruminants (e.g., Mogues 2011; Jalan and Ravallion 2002). Mogues (2011) highlights the relatively higher importance of small ruminants for managing weather shocks compared to large ruminants.

A long-standing finance literature documents that in the presence of idiosyncratic income risk, individuals tend to hold a higher share of their assets in less productive liquid forms (e.g., Carrol 1997; Carroll and Samwick 1997). We explicitly test this hypothesis considering livestock as a major form of assets (as well as source of income and insurance) for rural households and rainfall risk as an important source of income risk. We anticipate that those households exposed to unpredictable weather (rainfall) conditions are more likely to invest in livestock types that can be liquidated easily, for example, small ruminants. Of course, these responses and the effects of weather conditions depend on a household's resilience to weather shocks. Households with other mechanisms and sources of protection against weather shocks may not draw on livestock assets to smooth consumption during drought. This implies that the response and effects of rainfall uncertainty on livestock investments can vary across farming systems and livelihood zones.

The next rows of Table 2.2 provide information on modern livestock input use. The LSMS-ISA livestock modules ask for the breed type of each livestock households own – in particular, whether a specific livestock type is exotic, hybrid, or traditional breed. Not surprisingly, most households own traditional breeds, with only about 2 percent exotic breeds and 3 percent hybrid breeds. This is consistent with other datasets from Ethiopia and the assertion that limited availability and low adoption of improved livestock inputs and breeds are key constraints and explanations for existing low productivity of the livestock sector in Ethiopia (e.g., Duncan et al. 2013; Makoni et al. 2013; Gebremedhin et al. 2017). One of our hypotheses in this paper relates to the distribution of modern livestock input use across varying access to markets and weather conditions. We expect that those households with access to markets are more likely to access improved livestock breeds and, hence, potentially keep more productive livestock varieties. We anticipate that those households experiencing unpredictable weather (rainfall) conditions are less likely to invest in improved livestock inputs. The discouraging effect of rainfall variability on agricultural investment decisions, mainly crop production decisions and investments, has been documented by several studies (Lamb 2003; Alem et al. 2010; Dercon and Christiaensen 2011; Abay et al. 2018). However, it remains unclear if such patterns and adverse effects of rainfall variability extend to livestock investments.

The last rows of Table 2.2 provide households' production and marketing decisions over the last 12 months, focusing on animal source foods, mainly milk and butter.[14] More than half of the households have produced milk over the last 12 months even as market participation for selling milk remains low, especially for the non-ASAL regions. Similarly, about 37 percent of households have produced butter, with some significant variations across livelihood zones. Interestingly, butter marketing practices are much higher than for milk – more than half of butter producers have sold

[14] Milk and butter are the most marketed dairy products in Ethiopia (Gebremedhin et al. 2017).

butter. This is consistent with the empirical evidence by Gebremedhin et al. (2017), who found that butter is the most marketed dairy product in Ethiopia. However, there exists significant differences in butter production and butter marketing among farming systems. While milk production and marketing rates are relatively higher in the ASAL regions, butter production and marketing rates are much higher in the non-ASAL regions of Ethiopia. Our final hypothesis relates to the distribution of these production and marketing decisions across households with varying (access to) markets and weather conditions. We hypothesize that those households located in remote areas and, hence, with limited access to markets are less likely to participate in livestock marketing. Similarly, households' production and marketing decisions are expected to respond to weather conditions.

3. ESTIMATION AND EMPIRICAL STRATEGY

We identify three testable hypotheses on the interaction between markets, weather and livestock production decisions. These hypotheses are given below:

> **Hypothesis 1:** Increased access to markets increases market-oriented livestock production systems and investment in modern livestock inputs.
>
> **Hypothesis 2:** Weather risk affects livestock production orientation, investment in modern livestock inputs as well as livestock portfolio composition.
>
> **Hypothesis 3:** Access to markets and favorable weather conditions encourages marketing of livestock products.

Below we describe our empirical strategies to examine these hypotheses. Although, our key measures and indicators of access to markets and weather risk are commonly argued to be exogenous, the empirical relationships in the above three hypotheses remain informative even in the absence of causality.

3.1. Access to markets, weather risk, and livestock production orientation

As shown in Table 2.2, the LSMS-ISA data elicit farmers' main purpose of livestock production using farmers' self-reporting. Respondents choose among the seven main purposes and production orientations listed. For convenience, we narrow down these categories into four categories, by merging slightly similar production objectives and orientations. (Other types of classifications and associated results appear in the Appendix.) As discussed, these four categories include market-related, non-market related, precautionary savings and insurance, and farming-oriented livestock production decisions. In our first hypothesis, we are particularly keen on the distinction between market-oriented production systems and non-market related production orientations. These four production orientations can be modelled as a multinomial outcome using the following type of (latent) utility maximization framework:

$$U_{hlp} = \beta_{0p} + \beta_{1p} market_h + \beta_{2p} weather_h + \beta_{3p} Livestock\ type_{hl} + \beta_{4p} X_h + \varepsilon_{hlp} \quad (1)$$

U_{hlp} represents the utility that a household (*h*) generates from a specific type of livestock (*l*) associated with service or production choice (*p*). The first term in equation (1) captures constant terms for each production choice, while the second and third terms are measures of our key variables interest, distance to nearest market and weather conditions, respectively. As these production decisions are usually made and elicited for each type of livestock, we can control for livestock type dummies in the above specification, as captured by the fourth term in equation (1). X_h stands for other observable factors that affect this utility and, hence, households' livestock production orientations. These observable factors include household-related characteristics as well as biophysical and spatial attributes of the production environment. ε_{hlp} stands for other unobserved factors that may influence the utility function and production orientation. The utility maximization framework above assumes that households engage in the particular type of livestock production strategy that gives them the highest utility. Assuming that the error terms ε_{hlp} follow extreme value distribution, households' production orientation decision can be modelled as a standard multinomial logit probability distribution.[15]

By estimating the empirical specification in equation (1), we can test our first hypothesis on the interaction between markets and livestock production decisions. For instance, considering the production decisions in Table 2.2, we expect that those households with access to markets are more likely to produce livestock for markets, while those households with limited access to markets are more likely to produce livestock for non-market related purposes. This empirical specification can also inform our second hypothesis on the implication of weather risk on livestock production orientation. More specifically, unpredictable weather is expected to discourage market-oriented livestock production while potentially encouraging livestock production for precautionary savings and insurance. In the interest of uncovering the response and purpose of livestock production across different livelihood zones, we estimate the specification in equation (1) separately for households in ASAL regions and for households in non-ASAL regions of Ethiopia.

3.2. Access to markets, weather risk, and livestock ownership

Our second hypothesis explores the interaction among markets, weather and livestock ownership. We consider two outcomes related to households' livestock ownership and production decisions, improved livestock input use and livestock portfolio allocation across different livestock groups. The LSMS data provide detail on households' portfolio of livestock ownership, their types, and the herd size associated with each animal type. We have information on whether each animal type is a traditional breed, exotic, or hybrid. We generate indicator variables for exotic and hybrid breeds as well as intensive margin measures using the share of these improved livestock breeds. We then model these extensive and intensive margin decisions as a function of access to market and weather conditions using the following estimable equation.

$$y_{hlt} = \beta_0 + \beta_1 market_{ht} + \beta_2 weather_{ht} + \beta_3 Livestock\ type_{hlt} + \beta_4 X_{ht} + \varepsilon_{hlt} \qquad (2)$$

Where y_{hlt} now stands for indicator variables for modern livestock input use decisions associated with household *h*, livestock type *l*, and year *t.* These indicator variables include a binary indicator for exotic and hybrid livestock species, as well as the shares of these improved breeds among livestock types the household own. All other notations are similar to those described in section 3.1.

We estimate similar empirical specifications for characterizing and modelling households' livestock ownership and corresponding portfolio allocation. A households' livestock portfolio allocation decisions may not be independent among each other, necessitating joint estimations of these ownership and allocation decisions. We thus estimate the following seemingly unrelated regression (SUR) specification for each livestock group:

$$l_{hlt} = \beta_0 + \beta_1 market_{ht} + \beta_2 weather_{ht} + \beta_3 X_{ht} + \varepsilon_{hlt} \qquad (3)$$

Where l_{hlt} represents household's (*h*) livestock ownership or share of livestock ownership allocated in a specific type of livestock (*l*) and year (*t*). We measure livestock ownership in each of following five livestock groups – cattle, small ruminants, camels, poultry, and equines. As shown in Table 2.2, we also compute the share of livestock ownership (in terms of TLU) allocated in each livestock group. All other notations are similar to those in equation (1) and (2). Estimating the empirical specifications in equations (2) and (3) can inform our second hypothesis on the implication of

[15] Households production choice probabilities can be expressed as

$$P_{hp} = \frac{e^{(\beta_{0p} + \beta_{1p} market_h + \beta_{2p} weather_h + \beta_{3p} Livestock\ type_{hlp} + \beta_{4p} X_p + \varepsilon_{hlp})}}{\sum_p e^{(\beta_{0p} + \beta_{1p} market_h + \beta_{2p} weather_h + \beta_{3p} Livestock\ type_{hlp} + \beta_{4p} X_h + \varepsilon_{hlp})}},$$

where P_{hp} stands for probability of engaging in a specific production strategy.

weather risk on investments in modern livestock inputs and livestock portfolio allocation. We note that as distance to markets and weather risk are less likely to vary within short period of time, we are not controlling for household fixed effects in the empirical specifications in equations (2) and (3).

3.3. Access to markets, weather risk, and livestock marketing decisions

Our third hypothesis involves exploring the interaction between access to markets, weather, and households' livestock marketing decisions. For this purpose, we focus on households' production and marketing decisions associated with animal source foods (ASF), mainly focusing on milk and butter. As shown in Table 2.2, our data provide information on whether households have produced milk or butter as well as whether they have ever sold these products. For those producing these ASF, we consider two market participation outcomes for each ASF – whether they have sold their products and the share of production sold (for those selling ASF). Households' marketing decisions are expected to depend on production potential and other shocks that may affect both production and market participation. We thus model these production and marketing decisions sequentially in a triple hurdle framework (e.g., Burke et al. 2015).[16] We first model households' production decision using the following empirical specification:

$$ASF_{ht} = \beta_0 + \beta_1 market_{ht} + \beta_2 weather_{ht} + \beta_3 X_{ht} + \varepsilon_{ht} \quad (4)$$

Where ASF_{ht} is an indicator variables for households' production of milk or butter. For each livestock product (milk or butter), we observe households' production decisions as binary outcomes. Thus, we estimate the specification in equation (4) using a binary probit model, which characterizes the probability of producing a specific type of animal source food.

The sequentially next marketing decisions can be modeled using the following specification:

$$m_{ht} = \beta_0 + \beta_1 market_{ht} + \beta_2 weather_{ht} + \beta_3 X_{ht} + \varepsilon_{ht} \quad (5)$$

Where m_{ht} now represents households' marketing decision, measured by an indicator variable for participation in the market for sale of ASF.

Our third stage estimation involves characterizing households' intensive margin of market participation, share of production sold (S_{ht}), for those households participating in dairy markets. We thus estimate the following specification.

$$S_{ht} = \beta_0 + \beta_1 market_{ht} + \beta_2 weather_{ht} + \beta_3 X_{ht} + \varepsilon_{ht} \quad (6)$$

Because of the sequential or interrelated production and marketing decisions, error terms in equations (4), (5), and (6) are expected to be correlated.

We can estimate the empirical specifications in equations (4), (5), and (6) jointly using maximum likelihood estimation or through a stepwise and separate regressions. We follow the latter approach and, hence, estimate a first stage probit regression for characterizing households' production decisions. We then compute the inverse Mills ratio from this first stage regression to be used in our second and third stage regressions. Our second stage estimation entails estimating a probit model characterizing households' market participation decisions, from which we compute another inverse Mills ratio to be used in our third stage estimation. Our third stage estimation involves a linear regression characterizing the share of production sold, for those households selling their ASF. By including the inverse Mills ratio in the second and third stage estimations, we can tell whether the error terms associated with our production and marketing decisions are correlated. To facilitate empirical identification, it is usually advisable to include some explanatory variables that only affect the production decision but does not affect the marketing decision of households through other channels. These variables should satisfy the usual exclusion restriction. Following Burke et al.

[16] Alternatively, this may also be motivated and modelled under the traditional Heckman sample selection framework (Heckman 1979).

(2015) we include long-term previous rainfall variability measures in our production equation and exclude this in the marketing decision equations.

4. ESTIMATION RESULTS AND DISCUSSION

4.1. Markets, weather, and livestock production orientation

This section provides estimation results on the associations between market access and weather shocks and the livestock production orientation of the survey households. Table 4.1 presents the average marginal effects associated with the multinomial logit model specified in equation (1), while marginal effects from a binary probit model for market-related versus other orientations are given in Table A1 in the Appendix. In all our regressions we control for the list of household characteristics in Table 2.1 as well as regional and agro-ecological dummies. To conserve space, we only report and discuss marginal effects associated with our key variables of interest (access to market and weather conditions), while our full results are reported in Tables A2 to A4 in the Appendix. Households' access to market is measured by the Euclidean distance to the nearest permanent market, while weather condition is measured using the coefficient of variation rainfall over the ten years prior to enumeration. Following the discussion in Section 2, marginal effects are computed for each of the four major production orientations as well as for the more exhaustive seven main production choices given in Table 2.2.[17] The four major production orientations are market-related, non-market related, precautionary savings and insurance, and farming. We estimate marginal effects for the full sample (Panel A of Table 4.1) as well as for the sub-sample of households from the ASAL (Panel B) and from the non-ASAL regions (Panel C).

Consistent with hypothesis 1, access to markets appears to be important input in influencing the livestock production orientation of the sample households. The results in Panel A of Table 4.1 show that those households with access to markets are more likely to engage in livestock production for markets, while those households with limited access are more likely to engage in livestock production for non-market related and other objectives. Those households located in remote areas are more likely to produce livestock for precautionary savings and insurance purposes. However, the size of the effects are relatively small.

Households' livestock production response to market access are broadly comparable and consistent across the ASAL and non-ASAL regions of Ethiopia, except for slight differences in magnitudes. This suggests that livestock production responds to markets in both the ASAL and non-ASAL regions, albeit slightly differently.[18] This has important implications in terms of highlighting the potential of rural markets to improve the production orientation and production choices of livestock producers. From a development perspective, the evidence that households with improved access to markets focus their livestock production for markets imply that rural markets can impact the income and welfare of livestock herders by shaping their production choices and orientation.

The second row of Table 4.1 provides estimates associated with the response of livestock producers to weather conditions, measured by rainfall variability. Consistent with our second hypothesis, Panel A of Table 4.1 shows that households exposed to more unpredictable rainfall conditions are less likely to engage in livestock production for markets. Rather they are more engaged in livestock production for non-market and for precautionary savings and insurance purposes. Those households exposed to variable rainfall are also more likely to engage in livestock production for farming purposes (crop agriculture).

[17] Marginal effects for the seven categories are given in Table A5 in the Appendix.

[18] This confirms previous evidence highlighting livestock production in east Africa lacks market-orientation, implying that livestock production might not be sufficiently responsive to markets (e.g., Barrett et al. 2006; Negassa and Jabbar 2008).

Table 4.1: Average marginal effects of markets and weather conditions on the primary purpose of livestock production

Explanatory variables	(1) Market-related	(2) Non-market-related	(3) Precautionary savings and insurance	(4) Crop agriculture
Panel A: Marginal effects for the full sample				
Ln (distance to market, km)	-0.062***	0.041***	0.018***	0.003
	(0.006)	(0.006)	(0.004)	(0.004)
CV of rainfall past 10 years	-1.351***	0.394***	0.590***	0.367***
	(0.143)	(0.142)	(0.091)	(0.095)
Includes A-controls; Observations: 14,652				
Panel B: Marginal effects for the ASAL sub-sample				
Ln (distance to market, km)	-0.069***	0.060***	0.024***	-0.015**
	(0.010)	(0.010)	(0.006)	(0.006)
CV of rainfall past 10 years	-0.566**	-0.889***	2.202***	-0.748***
	(0.252)	(0.256)	(0.141)	(0.148)
Includes B-controls; Observations: 5,851				
Panel C: Marginal effects for the non-ASAL sub-sample				
Ln (distance to market, km)	-0.056***	0.026***	0.021***	0.008
	(0.007)	(0.007)	(0.006)	(0.005)
CV of rainfall past 10 years	-1.241***	0.757***	-0.364***	0.848***
	(0.172)	(0.165)	(0.121)	(0.123)
Includes B-controls; Observations: 8,801				

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: The values represent average marginal effects from a multinomial logit regression. Standard errors in parentheses.
A-controls include: animal type dummies, regional dummies, household level characteristics, and agro-ecological zones dummies.
B-controls include: animal type dummies, regional dummies, and household level characteristics.
ASAL = arid and semi-arid lands; CV = coefficient of variation; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

However, as shown in Panel B and C of Table 4.1, these responses and patterns vary across livelihood zones.[19] In the ASAL regions where livestock herding remains predominantly the largest source of livelihood and employment, households use livestock production as a precautionary savings and insurance mechanism. In these more arid regions, weather variability is strongly and positively associated with livestock production for self-insurance against drought and rainfall shocks. As these regions are known for limited crop production practices, rainfall uncertainty further discourages livestock production for farming purposes. This is not surprising as households in the ASAL regions have limited livelihood options and potential to diversify their production portfolio.

On the other hand, these patterns reverse as we move to Panel C of Table 4.1. In the non-ASAL regions of Ethiopia, rainfall variability induces livestock production for farming (crop agriculture), while also discouraging livestock production for markets. Similarly, those households living in these regions and exposed to more variable weather conditions are relatively less likely to engage in livestock production for precautionary savings and insurance. Households in these non-ASAL regions practice mixed livelihood and farming systems, which may offer them multiple options to manage and cope with rainfall shocks. Overall, these results highlight that livestock producers do respond to weather conditions by shaping their production choices. However, the responses of households vary across livelihood zones and livelihood strategies. Those households with alternative and mixed livelihood strategies seem to be less sensitive to weather uncertainty, while households in the ASAL regions of Ethiopia, which are mostly pastoralists, seem to have limited options, other than their livestock, to manage rainfall shocks.

[19] These patterns are also observed when we use the exhaustive list of production orientations (see Table A5 in the Appendix).

4.2. Markets, weather, and livestock investment and ownership

Table 4.2 reports the estimation results associated with the effect of access to markets and weather conditions on households' investment in improved livestock inputs. These are results from equation (2), where we examine livestock producers' propensity to use and, if so, the intensity of use of modern livestock inputs as a function of distance to market and weather conditions as well as other livestock and household characteristics. We measure adoption of improved livestock inputs using indicator variables for ownership of exotic and hybrid livestock as well as the share of these types of animals in households' livestock asset portfolio. We run these estimations separately for those households from the ASAL and non-ASAL regions of Ethiopia. Panel A provides estimates for the ASAL regions while Panel B reports results for the non-ASAL regions.

Table 4.2: Access to markets, weather, and their implication on modern livestock input use

Explanatory variables	(1) Exotic livestock	(2) Share of exotic livestock	(3) Hybrid livestock	(4) Share of hybrid livestock	(5) Exotic or hybrid livestock
			Panel A: Effects for the ASAL sub-sample		
Ln (distance to market, km)	-0.011***	-0.011***	-0.005	-0.004	-0.007
	(0.004)	(0.003)	(0.005)	(0.003)	(0.006)
CV of rainfall past 10 years	-0.058	-0.027	-0.355***	-0.313***	-0.439***
	(0.097)	(0.089)	(0.111)	(0.106)	(0.135)
Controls?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*7,412*	*7,412*	*4,639*	*4,639*	*4,802*
			Panel B: Effects for the non-ASAL sub-sample		
Ln (distance to market, km)	-0.000	0.001	-0.005	-0.004	-0.000
	(0.003)	(0.003)	(0.004)	(0.003)	(0.005)
CV of rainfall past 10 years	0.069	0.070	-0.066	-0.003	-0.118
	(0.057)	(0.051)	(0.109)	(0.101)	(0.106)
Controls?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*10,892*	*10,892*	*6,923*	*6,923*	*7,021*

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: Values for column (1), (3) and (4) are linear probability model estimates, while the results in column (2) and (4) come from linear regression estimations. Controls include year, regional, and agro-ecological dummies and household characteristics. Standard errors, clustered at household level, are given in parentheses.
ASAL = arid and semi-arid lands; CV = coefficient of variation; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Consistent with our first hypothesis, the results in Panel of A of Table 4.2 show that access to markets improve adoption of modern livestock inputs, while unpredictable rainfall conditions discourage investments in these modern livestock inputs. Despite the relatively small magnitudes of these effects on the use of modern livestock inputs, they are consistent with the general implication of remoteness on the distribution of modern agricultural inputs, on their prices, and on the profitability of their use (e.g., Minten et al. 2013). The adverse effects of rainfall variability on livestock investment is also consistent with previous evidence of negative impacts of weather risk on agricultural investments (Lamb 2003; Alem et al. 2010; Dercon and Christiaensen 2011: Abay et al. 2018). However, Panel B of Table 4.2 shows that these effects are only significant in the ASAL regions, implying variation in responses across livelihood zones. In the non-ASAL regions, which mainly rely on mixed livelihood strategies, modern livestock input use is not responsive to market and weather conditions. This is not surprising given that households in the non-ASAL regions have alternative livelihood strategies to livestock production and other options to deal with climate variability.

In Table 4.3 we document somewhat similar effects of markets and weather conditions on herd size and livestock portfolio allocation. These regressions involve livestock ownership of each type of livestock as a function of markets and weather conditions as well as other additional household, regional, and agroecological characteristics. We run these regressions separately for each livestock group: large ruminants (cattle), small ruminants (goats and sheep), camels, poultry, and equines. We employ an inverse hyperbolic transformation of values for each livestock group. Panel A of Table 4.3 provides the effects of markets and rainfall conditions on livestock ownership for the full sample while Panel B and C provide corresponding estimates for the ASAL and non-ASAL sub-samples, respectively. Panel A of Table 4.3 shows that those households living in remote areas are more likely to own more small ruminants, camels, and equines. Those households exposed to more variable rainfall are more likely keep a larger number of small ruminants, which are considered to be more liquid than other livestock types (Jalan and Ravallion 2001). However, these effects are more pronounced and more visible in the ASAL sub-sample.

Table 4.3: Access to markets, weather, and their implication on number of livestock owned, by type

Explanatory variables	(1) Large ruminants	(2) Small ruminants	(3) Camels	(4) Poultry	(5) Equines
			Panel A: Effects for the full sample		
Ln (distance to market, km)	0.006	0.121***	0.012*	-0.050**	0.049***
	(0.016)	(0.021)	(0.006)	(0.021)	(0.010)
CV of rainfall past 10 years	-0.438	1.432***	-0.262*	-0.008	-0.214
	(0.382)	(0.511)	(0.151)	(0.517)	(0.241)
Includes controls; Observations: 6,560					
			Panel B: Effects for the ASAL sub-sample		
Ln (distance to market, km)	-0.028	0.108***	0.031*	-0.122***	-0.007
	(0.028)	(0.040)	(0.017)	(0.036)	(0.018)
CV of rainfall past 10 years	-2.738***	3.944***	-0.437	1.091	-1.267***
	(0.708)	(1.006)	(0.420)	(0.908)	(0.446)
Includes controls; Observations: 2,512					
			Panel C: Effects for the non-ASAL sub-sample		
Ln (distance to market, km)	0.031	0.138***	0.007**	-0.017	0.082***
	(0.019)	(0.024)	(0.003)	(0.026)	(0.012)
CV of rainfall past 10 years	0.490	0.673	-0.144*	-0.548	0.254
	(0.454)	(0.583)	(0.074)	(0.637)	(0.288)
Includes controls; Observations: 4,048					

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: Parameter estimates come from seemingly unrelated regressions (SUR), which allows for correlated error terms. Controls include year, regional, and agro-ecological zone dummies and household characteristics. Standard errors are given in parentheses.
ASAL = arid and semi-arid lands; CV = coefficient of variation; * p < 0.10, ** p < 0.05, *** p < 0.01.

Table 4.4 presents additional confirming evidence on households' livestock portfolio allocation. In these regressions, we compute the share of livestock assets (measured in terms of TLU) allocated across four major livestock groups: large ruminants, small ruminants, poultry, and equines.[20] We then run the share of livestock portfolio allocated to a specific livestock group as a function of our key variables of interest as well as additional controls. Following our second hypothesis, unpredictable weather (rainfall uncertainty) is expected to influence livestock portfolio allocation.

[20] As shown in Table 2.2, the share of livestock assets allocated in camels is very low (on average close to zero) in the non-ASAL areas of Ethiopia. We thus dropped this livestock group from our regressions in Table 4.4.

Table 4.4: Access to markets, weather, and their implication on livestock portfolio allocation

Explanatory variables	(1) Large ruminants	(2) Small ruminants	(3) Poultry	(4) Equines
Panel A: Effects for the full sample				
Ln (distance to market, km)	-0.024***	0.020***	-0.008**	0.009***
	(0.006)	(0.004)	(0.004)	(0.003)
CV of rainfall past 10 years	-0.221	0.400***	-0.097	-0.062
	(0.136)	(0.107)	(0.090)	(0.066)
Includes controls; Observations: 6,332				
Panel B: Effects for the ASAL sub-sample				
Ln (distance to market, km)	-0.027***	0.022***	0.002	-0.004
	(0.010)	(0.008)	(0.006)	(0.005)
CV of rainfall past 10 years	-1.210***	1.320***	0.080	-0.218*
	(0.249)	(0.210)	(0.163)	(0.121)
Includes controls; Observations: 2,448				
Panel C: Effects for the non-ASAL sub-sample				
Ln (distance to market, km)	-0.021***	0.019***	-0.017***	0.017***
	(0.007)	(0.005)	(0.005)	(0.003)
CV of rainfall past 10 years	0.127	0.079	-0.214*	0.047
	(0.163)	(0.122)	(0.109)	(0.079)
Includes controls; Observations: 3,884				

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: Parameter estimates come from seemingly unrelated regressions (SUR), which allows for correlated error terms. Controls include year, regional, and agro-ecological zone dummies and household characteristics. Standard errors are given in parentheses.
ASAL = arid and semi-arid lands; CV = coefficient of variation; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The results in Table 4.4 show that those households exposed to more variable and unpredictable rainfall conditions are less likely to invest in large ruminants but are more likely to invest in small ruminants. This is consistent with previous evidence highlighting the relatively high importance of small ruminants for managing weather shocks (Mogues 2011). Consistent with the previous results, these responses and effects of weather variability are more visible in the ASAL regions of Ethiopia where livestock herding remains a dominant source of livelihood. Intuitively, these pieces of evidence imply that weather risk affects livestock portfolio allocation and associated livestock investments. This is consistent with our second hypothesis, and the broader finance literature which argue that income uncertainty can induce more investment and portfolio allocation in liquid, and potentially less productive, assets (Jalan and Ravallion 2001).

4.3. Markets, weather, and livestock marketing decisions

In Table 4.5, we provide evidence related to our third hypothesis, the implication of access to markets and weather conditions on livestock-byproduct marketing decisions. We estimate households' production and marketing decisions using a triple hurdle set of models. Unlike livestock production decisions, marketing decisions for animal source foods are expected to be more sensitive to short-term weather conditions than to long-term weather risk. For this reason, we generate an indicator variable for a recent rainfall shock and examine the response of households' production and marketing decisions to this exogenous rainfall shock. We construct this indicator by considering whether in the year before a survey round was implemented there, an enumeration area experienced annual rainfall more than one standard deviation below the long-term average rainfall.

Panel A of Table 4.5 provides estimates for milk production and marketing decisions while Panel B provides corresponding estimates associated with households' butter production and marketing decisions. To facilitate empirical identification, we include rainfall variability measures in the production decisions, but exclude them in the marketing decisions. While rainfall variability can affect production of animal source foods, it is less likely to explain marketing decisions, except through influencing production of these livestock products. The first three columns provide results for the ASAL sample while the last three columns report estimates for the non-ASAL sample. For both regions, the first column provides probit model estimates characterizing a binary decision for producing milk or butter. The second column reports probit model estimates associated with households' market participation while the third column provides linear regression coefficients for households' share of ASF production sold. The inverse Mills ratio appears to be significant in some of our specifications, justifying inclusion and control for this ancillary component in households' marketing decisions.

Table 4.5: Access to markets, weather, and their implication on households' marketing decisions

	(1)	(2)	(3)	(4)	(5)	(6)
	ASAL sub-sample			Non-ASAL sub-sample		
Explanatory variables	Produced (probit estimates)	Sold (probit estimates)	Share sold	Produced (probit estimates)	Sold (probit estimates)	Share sold
Panel A: Effects for milk production and marketing						
Ln (distance to market, km)	0.104*	-0.410***	-0.108	-0.019	-0.120*	-0.096**
	(0.057)	(0.082)	(0.066)	(0.036)	(0.065)	(0.039)
Recent rainfall shock, 0/1	-0.113	-0.873***	-0.311*	0.137	0.188	0.037
	(0.113)	(0.221)	(0.169)	(0.102)	(0.222)	(0.090)
CV of rainfall past 10 years	2.952**			0.621		
	(1.461)			(0.865)		
Inverse Mills ratio, $\widehat{IMR}$		-0.297	0.379		0.998*	0.271
		(0.477)	(0.260)		(0.535)	(0.347)
Controls?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*1,897*	*1,054*	*250*	*3,217*	*1,519*	*108*
Panel B: Effects for butter production and marketing						
Ln (distance to market, km)	0.029	-0.271***	-0.064	-0.022	-0.092*	-0.020
	(0.060)	(0.098)	(0.150)	(0.036)	(0.053)	(0.016)
Recent rainfall shock, 0/1	-0.075	-0.516***	-0.157	-0.035	-0.166	-0.095**
	(0.115)	(0.194)	(0.323)	(0.101)	(0.155)	(0.040)
CV of rainfall past 10 years	-0.329			3.836***		
	(1.521)			(0.851)		
Inverse Mills ratio, $\widehat{IMR}$		-0.070	0.482		-1.391***	0.408***
		(0.715)	(0.909)		(0.413)	(0.113)
Controls?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*1,879*	*543*	*237*	*3,164*	*1,306*	*742*

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: Results in columns (1), (2), (4), and (5) represent binary probit model coefficients, while those in columns (3) and (6) come from linear regressions. Controls include year, regional, and agro-ecological zone dummies and household characteristics. Standard errors given in parentheses.
$\widehat{IMR}$ stands for inverse Mills ratio. ASAL = arid and semi-arid lands; CV = coefficient of variation; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Panel A of Table 4.5 shows that distance to market is weakly correlated with households' milk production decisions, while strongly and inversely corelated with their milk marketing decisions and outcomes. Those households living in remote areas are less likely to participate in milk marketing, selling a smaller share of their production. However, some of the third stage results are statistically insignificant, perhaps due to the limited sample sizes in these estimations.

Households' butter marketing decisions also respond to weather conditions and rainfall shocks. Households living in the ASAL regions produce and sell less butter when hit by drought or rainfall shocks. On the other hand, these types of droughts and rainfall shocks have mostly negligible impacts for those households living in the non-ASAL regions. In fact, the effect of rainfall variability on production of ASF seems to vary across products and farming systems. For instance, in the ASAL regions, which are more known for milk production than for butter production, milk production responds to rainfall variability. Households in the non-ASAL regions are known for butter production, and their butter production functions are more responsive to rainfall variability than are their milk production functions.

Overall, the evidence from this section supports our findings in earlier sections that weather risk is an important production risk, but that there is variation between livelihood zones in how households respond to that production risk. Those households that are more reliant on livestock production respond more strongly to both weather risk as well as to access to markets. Indeed, weather shocks are more impactful on households' livestock production and marketing outcomes in the ASAL regions than in the non-ASAL regions. This is consistent with the extreme poverty rates and vulnerability to climate shocks commonly documented among the ASAL communities in east Africa (e.g., Thornton et al. 2002; Thornton et al. 2006).

5. CONCLUDING REMARKS

In this paper we study whether and how livestock production responds to access to markets and weather risk. We also explore whether such responses vary across livelihood zones and production systems. We study these research questions using longitudinal household survey data from Ethiopia, which provide detailed information on households' livestock production, ownership, marketing, and consumption decisions. We employ three waves of the Living Standard Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) for Ethiopia. Investigating the impact of markets and weather conditions to shape livestock production and investment in the context of Ethiopia is appealing because, despite abundant livestock resource, Ethiopia's value of livestock production and consumption remains far below production potentials. This has hampered the overall contribution of the livestock sector to the national economy.

We study alternative measures and indicators of livestock ownership, production, and marketing decisions of households. We characterize livestock production and investment decisions in terms of: (a) production orientation, (b) livestock portfolio allocation across alternative livestock types, and (c) investment in improved livestock inputs. Similarly, we characterize households' marketing decisions in terms of market participation for selling milk and butter. In the interest of uncovering potential heterogeneities in the response of livestock production decisions across farming systems and livelihood zones, we separately estimate responses for the arid and semi-arid lands (ASAL) and non-ASAL regions.

We find that smallholders' livestock production and marketing decisions do respond to markets and weather conditions. Livestock keepers located in remote areas and those exposed to unpredictable rainfall spells are less likely to engage in market-oriented livestock production, both in terms of sale of live animals and milk and butter. Greater access to markets is also positively related to the use of modern livestock breeds. We also find that livestock production significantly responds to weather risk. Those households living in variable and unpredictable weather conditions are more likely to engage in livestock production as precautionary savings and insurance against shocks. Similarly, rainfall uncertainty discourages investments in modern livestock inputs while also influencing livestock portfolio allocation. Consistent with the long-standing finance literature, households exposed to more unpredictable rainfall are more likely to invest in livestock types that can be easily liquidated. This implies that livestock producers factor in the unpredictability of their production environment when making decisions about which type and how much livestock assets to hold. However, these responses and patterns vary across livelihood zones and most of these stylized responses and impacts are only visible and significant in the ASAL regions of Ethiopia where extensive, rainfall reliant, livestock herding remains a dominant source of livelihood. These results highlight the adverse effects of weather risk in discouraging market-oriented livestock production and investments in livestock production. This reinforces recent attempts to mitigate livestock herders' production risks in the ASAL regions of east Africa through the use of index-based livestock insurance (Chantarat et al. 2013; Jensen and Barrett 2016; Jensen et al. 2017). The heterogeneities in the impact of weather risk among farming systems and livelihoods further highlight the need for more tailored livestock sector policies and interventions (Pica-Ciamarra et al. 2015).

However, this study does have some limitations. Despite the commonly held view that access to markets and weather risk are largely exogenous to households' production decisions, further studies using alternative sources of exogenous variation are required to confirm our findings and causal inference. Furthermore, our reduced form approach does not reveal much about the mechanisms and potential channels through which weather risk and markets may influence livestock production and marketing decisions. We hope that further studies will explore the nature and potential mechanisms in these interactions among markets, weather, and livestock production.

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APPENDIX

Table A1: Average marginal effects of markets and weather conditions on binary market-related indicator of livestock production orientation

Explanatory variables	(1) Full sample	(2) ASAL sub-sample	(3) Non-ASAL sub-sample
Ln (distance to market, km)	-0.059***	-0.067***	-0.051***
	(0.006)	(0.010)	(0.007)
CV of rainfall past 10 years	-1.306***	-0.897***	-1.163***
	(0.143)	(0.242)	(0.173)
Animal type dummies	*Yes*	*Yes*	*Yes*
Region dummies	*Yes*	*Yes*	*Yes*
Household controls	*Yes*	*Yes*	*Yes*
Agro-ecological zones	*Yes*	*Yes*	*Yes*
Observations	*14,644*	*5,851*	*8,801*

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: The binary market-related indicator of livestock production orientation takes a value of one if the main purpose for livestock production reported by the sample household was either "sale of live animals" or "sale of livestock products".
These results represent marginal effects from (binary) probit regressions characterizing market-related livestock production orientation. Standard errors in parentheses. ASAL = arid and semi-arid lands; CV = coefficient of variation; * p < 0.10, ** p < 0.05, *** p < 0.01.

Table A2: Average marginal effects for full covariates for the full sample

Explanatory variables	(1) Market-related	(2) Non-market-related	(3) Precautionary savings and insurance	(4) Crop agriculture
Ln (distance to market, km)	-0.062***	0.041***	0.018***	0.003
	(0.006)	(0.006)	(0.004)	(0.004)
CV of rainfall past 10 years	-1.351***	0.394***	0.590***	0.367***
	(0.143)	(0.142)	(0.091)	(0.095)
Male household head, 0/1	-0.027**	0.008	0.011	0.007
	(0.011)	(0.011)	(0.008)	(0.008)
Age of household head, years	0.001**	-0.001***	0.001***	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Household head is literate, 0/1	0.023***	-0.029***	0.008	-0.002
	(0.008)	(0.008)	(0.006)	(0.006)
Household size, members	-0.003*	0.007***	-0.001	-0.003**
	(0.002)	(0.002)	(0.001)	(0.001)
Ln (livestock assets, TLU)	-0.004	0.005	0.007*	-0.009*
	(0.006)	(0.006)	(0.004)	(0.005)
Ln (farm size, ha)	-0.022***	0.001	0.006**	0.015***
	(0.003)	(0.003)	(0.002)	(0.002)
Has access to credit from formal source, 0/1	-0.009	0.002	-0.008	0.015*
	(0.014)	(0.014)	(0.010)	(0.009)
Has access to micro-finance facilities, 0/1	-0.054***	0.060***	0.024***	-0.029***
	(0.009)	(0.009)	(0.006)	(0.006)
Household owns phone, 0/1	-0.006	0.009	-0.019***	0.016***
	(0.008)	(0.008)	(0.006)	(0.005)
Observations: 14,652				

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: Table provides marginal effects from a multinomial logit regression characterizing households' livestock production orientation. Standard errors are given in parentheses. TLU = tropical livestock unit, CV = coefficient of variation; * p < 0.10, ** p < 0.05, *** p < 0.01.

Table A3: Average marginal effects for full covariates for the arid and semi-arid lands (ASAL) sub-sample

Explanatory variables	(1) Market-related	(2) Non-market-related	(3) Precautionary savings and insurance	(4) Crop agriculture
Ln (distance to market, km)	-0.069***	0.060***	0.024***	-0.015**
	(0.010)	(0.010)	(0.006)	(0.006)
CV of rainfall past 10 years	-0.566**	-0.889***	2.202***	-0.748***
	(0.252)	(0.256)	(0.141)	(0.148)
Male household head, 0/1	-0.040**	0.017	0.019	0.005
	(0.017)	(0.017)	(0.012)	(0.011)
Age of household head, years	0.002***	-0.002***	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Household head is literate, 0/1	0.079***	-0.091***	0.021**	-0.009
	(0.013)	(0.014)	(0.008)	(0.008)
Household size, members	-0.005*	0.008***	0.003*	-0.005***
	(0.003)	(0.003)	(0.002)	(0.002)
Ln (livestock assets, TLU)	-0.022**	0.030***	0.013**	-0.021***
	(0.010)	(0.010)	(0.006)	(0.007)
Ln (farm size, ha)	-0.018***	-0.007	0.003	0.022***
	(0.005)	(0.005)	(0.003)	(0.003)
Has access to credit from formal source, 0/1	0.044*	-0.081***	0.049***	-0.011
	(0.023)	(0.024)	(0.013)	(0.013)
Has access to micro-finance facilities, 0/1	-0.131***	0.091***	0.004	0.035***
	(0.018)	(0.018)	(0.011)	(0.010)
Household owns phone, 0/1	0.037***	-0.027**	-0.033***	0.023***
	(0.013)	(0.013)	(0.008)	(0.008)
Observations: 5,851				

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: Table provides marginal effects from a multinomial logit regression characterizing households' livestock production orientation. Standard errors are given in parentheses. TLU = tropical livestock unit, CV = coefficient of variation; * p < 0.10, ** p < 0.05, *** p < 0.01.

Table A4: Average marginal effects for full covariates for the non-arid and semi-arid lands (non-ASAL) sub-sample

Explanatory variables	(1) Market-related	(2) Non-market-related	(3) Precautionary savings and insurance	(4) Crop agriculture
Ln (distance to market, km)	-0.056***	0.026***	0.021***	0.008
	(0.007)	(0.007)	(0.006)	(0.005)
CV of rainfall past 10 years	-1.241***	0.757***	-0.364***	0.848***
	(0.172)	(0.165)	(0.121)	(0.123)
Male household head, 0/1	-0.022	-0.002	0.008	0.016
	(0.014)	(0.013)	(0.010)	(0.010)
Age of household head, years	-0.000	-0.000	0.001***	-0.001**
	(0.000)	(0.000)	(0.000)	(0.000)
Household head is literate, 0/1	-0.015	0.014	0.008	-0.007
	(0.011)	(0.011)	(0.008)	(0.008)
Household size, members	-0.002	0.004*	-0.001	-0.000
	(0.002)	(0.002)	(0.002)	(0.002)
Ln (livestock assets, TLU)	0.009	-0.009	-0.003	0.003
	(0.008)	(0.008)	(0.006)	(0.007)
Ln (farm size, ha)	-0.018***	0.005	-0.002	0.015***
	(0.005)	(0.005)	(0.003)	(0.003)
Has access to credit from formal source, 0/1	-0.016	0.047***	-0.050***	0.019
	(0.018)	(0.017)	(0.017)	(0.012)
Has access to micro-finance facilities, 0/1	-0.037***	0.063***	0.034***	-0.060***
	(0.011)	(0.011)	(0.007)	(0.008)
Household owns phone, 0/1	-0.037***	0.036***	-0.011	0.012*
	(0.010)	(0.010)	(0.008)	(0.007)
Observations: 8,801				

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: Table provides marginal effects from a multinomial logit regression characterizing households' livestock production orientation. Standard errors are given in parentheses. TLU = tropical livestock unit, CV = coefficient of variation; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A5: Average marginal effects of markets and weather conditions on livestock production choices

Explanatory variables	(1) Sale live	(2) Sale of animal source foods	(3) Food for family	(4) Precautionary savings and insurance	(5) Social status	(6) Crop	(7) Sale live
Panel A: Marginal effects for the full sample							
Ln (distance to market, km)	-0.033***	-0.025***	0.003	0.023***	0.016***	-0.000	0.016***
	(0.005)	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)	(0.005)
CV of rainfall past 10 years	-0.838***	-0.340***	0.676***	0.740***	-0.172**	0.134	-0.200*
	(0.125)	(0.104)	(0.063)	(0.091)	(0.082)	(0.092)	(0.117)
Includes controls for animal type, household characteristics, and regions. Observations: 14,652							
Panel B: Marginal effects for the ASAL sub-sample							
Ln (distance to market, km)	-0.029***	-0.041***	0.025***	0.024***	0.021***	-0.016***	0.016*
	(0.009)	(0.007)	(0.005)	(0.006)	(0.005)	(0.006)	(0.009)
CV of rainfall past 10 years	-0.301	-0.315*	0.023	2.193***	-0.157	-0.759***	-0.684***
	(0.223)	(0.186)	(0.117)	(0.141)	(0.151)	(0.148)	(0.221)
Includes controls for animal type, household characteristics, and regions. Observations: 5,581							
Panel C: Marginal effects for the non-ASAL sub-sample							
Ln (distance to market, km)	-0.037***	-0.016***	-0.010***	0.023***	0.015***	0.010*	0.017***
	(0.006)	(0.005)	(0.003)	(0.006)	(0.004)	(0.005)	(0.006)
CV of rainfall past 10 years	-1.016***	-0.188	0.977***	-0.348***	-0.244**	0.852***	-0.033
	(0.153)	(0.128)	(0.083)	(0.120)	(0.101)	(0.122)	(0.136)
Includes controls for animal type, household characteristics, and regions. Observations: 8,801							

Source: Analysis of Ethiopia LSMS-ISA survey data for 2011/12, 2013/14, and 2015/16.
Notes: this table provides marginal effects from a multinomial logit regression characterizing households' livestock production orientation. Standard errors in parentheses. ASAL = arid and semi-arid lands; CV = coefficient of variation; * p < 0.10, ** p < 0.05, *** p < 0.01.

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