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ABSTRACT. Livestock have long been considered as a buffer stock, though recent studies on asset smoothing suggest that the extent of use of livestock sale as self-insurance bifurcates between the asset rich (i.e., those with abundance of livestock to sustain their livelihoods) and the asset poor (i.e., those without enough livestock). Using two-period panel surveys of rural Ethiopia, this paper extends the discussion of the asset dynamics bifurcation by disaggregating rainfall shocks into drought- and flood-related ones. My empirical analysis implies that the asset rich sold their small livestock in the face of below-normal rainfalls, though the asset poor did not. Faced with above-normal rainfall shocks, on the other hand, the asset poor depleted their livestock. I discuss possible explanations for these results.

Key words: asset dynamics, buffer stock saving, livestock, natural disaster, Ethiopia

JEL Codes: C33, D15

1. Introduction

The impacts of climatic disasters on the welfare of rural households are substantial and can be persistently detrimental, especially where a range of insurance mechanisms are absent. Droughts and floods are the two common disasters widely observed in the Horn of Africa where seasonal rainfall variation has been intensified at increasing rate. For the period of 1990-2015, 46 natural disasters are reported in Ethiopia according to the emergency events database (EM-DAT), among which floods and droughts are the most frequently observed disasters accounting for 63 per cent of total disasters in Ethiopia. The scale of impacts of those two disasters, in terms of affected populations, are also the largest: approximately 129,150 population per flood and 5,421,320 population per drought were negatively impacted through these two disasters (Table 1). In addition to those frequent and mass-scale climate events, heavy reliance on rainfed farming and lack of flood-control interventions make Ethiopian farmers vulnerable to rainfall fluctuation.

Table 1. Natural disasters registered in EM-DAT database in Ethiopia (1990-2015)

Disaster	Frequency	Average affected population per one event
Drought	10	5,521,320
Flood	19	129,150
Epidemic	10	7,481
Volcanic activity	2	5,500
Landslide	2	97
Wildfire	1	5
Insect infestation	1	N/A
Mass movement (dry)	1	N/A

Source: Author's calculations based upon EM-DAT dataset.

Since the poor tend to have limited access to formal financial markets, buffer-stock saving and informal insurance mechanisms are the alternative coping strategies left to insulate the consumption from adverse income shocks. However, informal insurance mechanisms among villagers are not reliable against aggregate shocks where the peer villagers are also adversely affected by the shock. Self-insurance through destocking assets may cost reduced level of future consumption if the households are forced to destock their meagre productive assets. Hence, the extent of self-insurance through the sale of assets may be different based upon the level of initial endowment of liquid assets and the portfolio of them (i.e., cash, grain stocks, and livestock).

In this paper, I would like to compare the effects of different sets of climatic disaster on livestock holdings, a major liquid asset for rural Ethiopian households. Even with the recent rise in occurrence of climatic disasters driven by climate change, how the different sets of disasters affect the lives of rural households are not yet well investigated. A significant body of microeconomic research examines how households cope with aggregate and idiosyncratic shocks and long-term consequences of those shocks. However, comparative studies on different sets of disasters are largely limited to macroeconomic cross-country research (e.g., Sawada, Rima, & Kotera, 2011; Skidmore & Toya, 2002) and most of the microeconomic research examine either droughts (Carter & Lybbert, 2012; Dercon, 2004; Fafchamps, Udry, & Czukas, 1998; Hoddinott, 2006; Kazianga & Udry, 2006; Thiede, 2014) or heavy-rain related events (Kurosaki, 2015a; Miura, Kanno, & Sakurai, 2012). Two exceptions in efforts to examine welfare costs of different disasters are worth noting (e.g., Carter, Little, Mogues, & Negatu, 2007; Kurosaki, 2015b) though none of them directly compare the impacts of different disasters on asset-holdings.

A drought is an event which occurs after several bad rain seasons. Duration of a drought is longer than those of the other natural disasters, and the size of the affected population is often the largest, though it does not immediately damage public infrastructures (i.e., road and communication networks) and household productive and non-productive assets. Over-precipitation and subsequent floods may immediately affect the lives of households, damaging public infrastructure and household assets. Due to these differences in suddenness and duration of the impact, the affected households may react to each disaster differently.

Ethiopia has been suffering recurrent climatic disasters for a long time. Among others, droughts often led to the greatest famines in Ethiopia and left long-lasting impacts on economic growth. One of the survey collection years, 2010-2011 was the driest year on record, and this drought crisis affected 13 million people in the Horn of Africa (IASC, 2012). In Ethiopia, this drought mainly affected Eastern part of Ethiopia, where poor precipitation for two consecutive ploughing seasons, *meher* rain (June-September 2010) and *belg* rain

(February-May 2011)[1] left approximately 4.6 million people in need of humanitarian aid in 2011. Drought in 2010-2011 was an extreme case of climatic disasters observed during our survey periods. To a lesser extent, above-normal rainfall and subsequent disasters were observed in 2010 and 2013 in our sample areas. The data are therefore particularly appropriate to test whether livestock were de-accumulated against these below-normal and above-normal rainfall shocks.

This paper attempts to fill these gaps in the literature by investigating the following questions: what are the effects of above-normal and below-normal rainfall shocks on household livestock holdings? As previous empirical analysis predicts, do asset-poor households smooth their livestock in the face of aggregate rainfall shocks regardless of whether the aggregate shocks are below-normal or above-normal rainfall events? Drawing upon the panel data collected in the middle of a drought and an unusual heavy rainfall event, I investigate heterogeneity in livestock accumulation dynamics among different asset-holding levels. The rainfall data I use are collected and distributed for Ethiopian Early Warning System by the U.S. National Oceanic and Atmospheric Administration (NOAA). As I discuss later in section 4, the accuracy of the data enable us to control village-level rainfalls. I first

[1] There are two agricultural seasons in most part of crop-harvesting areas in Ethiopia: *Meher* and *Belg*. *Meher* is the main rainy season, and the area cultivated and the amount of crop produced in the *Meher* season accounted for 92.1 per cent of the total area cultivated and 96.9 per cent of total crop production (Taffesse, Dorosh, & Asrat, 2012).

estimate relative welfare impacts of two different rainfall shocks on livestock-holding dynamics, utilizing a dynamic panel data model. I then investigate whether the change in livestock holdings came from the sale of livestock or mere loss due to the disasters. Analysis of livestock accumulation with different asset-status subsamples reveals that the effects of above-normal and below-normal rainfall on livestock holdings differ over initial asset status. The households who had enough cattle power for ploughing before the drought of 2011 de-accumulated their small livestock holdings in the face of below-normal rainfall by increasing their sales, though those households without enough cattle for ploughing did not reduce their livestock holdings significantly in the face of below-normal rainfall. In contrast, the asset poor de-accumulated their small livestock in the face of above-normal rainfall, though the net-sale small livestock was not responsive to the above-normal rainfall. In sum, asset-accumulation dynamics differed not only by the difference in initial asset endowment but also the differences in scale and duration of the natural shocks.

The next section discusses how livestock sales are examined in the literature of consumption- and asset-smoothing and situates this article in this intellectual context. Rural Ethiopian setting and the data used in this study are described in Section3 and 4. Section 5 presents an empirical model of livestock holdings dynamics and investigates the effects of above-normal and below-normal rainfalls. The main analysis of the response of household livestock holdings to shocks is presented in Section 6. The final section concludes the paper.

2. Literature Review

Under severe credit constraints and the existence of frequent aggregate rainfall shocks, poor households in developing countries are often caught up in a situation where they found no other way but to self-insure themselves by selling their assets. At the occasion of idiosyncratic shocks, informal insurance arrangements among the peer villagers function well in rural villages where the risk of information asymmetry is minimized. However, in case of aggregate shocks whose adverse impacts extend to a large proportion of the affected villages, the informal insurance systems are not effective. Livestock are long believed to serve as a buffer stock against adverse income shocks in Sub-Sahara Africa[2], where other coping mechanisms do not work sufficiently.

However, a large body of empirical results suggest that households in developing areas do not always destock their livestock at the time of negative income shocks (Fafchamps et al., 1998). Zimmerman & Carter (2003) showed a theoretical possibility that the asset poor deliberately protect their productive assets (i.e., 'asset smoothing') as part of their optimal inter-temporal consumption strategy. Due to the existence of fixed cost for adoption of high productivity technology (i.e., use of two-ox plough), poor households in the vicinity of the essential asset level try to keep their productive assets by sacrificing current consumption.

[2] Buffer assets which offer low but stable returns (e.g., cash, grain stocks) and productive assets which offer high and variable returns (e.g., land, livestock) were separately analysed in the theoretical model developed by Zimmeman & Carter (2003).

The asset level around which the optimal intertemporal consumption strategy bifurcate is often referred as the dynamic asset poverty threshold (Micawber Threshold). Above this dynamic asset poverty threshold, a household accumulates assets and settles in a stable high level equilibrium while being below the threshold would mean that a household degrades their assets and falls into another stable low level equilibrium, a poverty trap (Carter & Barrett, 2006). Thus, the asset poor whose livestock holdings are around the threshold may not destock their productive assets and let the consumption level fluctuate. Empirical evidence that explores the asset poverty threshold supports the differences in use of livestock as a buffer stock among the asset poor and the asset rich (Carter & Lybbert, 2012). Hoddinott (2006) found that during the time of drought, half of asset-rich households sold their oxen but only 15 per cent of asset-poor households do so in Zimbabwe. Kazianga & Udry (2006) tested several possible motives behind inactive livestock sales in the face of a severe drought and found the strong evidence that a livestock reproduction strategy may determine the extent of liquidating livestock during the serious drought. In addition to the initial level of livestock holdings, the availability of social networks and non-farm employment also affect livestock management strategies differently among the asset poor and the asset rich (Mogues, 2004; Carter *et al.* 2007; McPeak & Barrett, 2001).

Different types of assets face different transaction costs, and thus difference in asset portfolios also can cause heterogeneity in use of livestock as a buffer stock. Unproductive liquid assets such as cash and grain stock are easier to use without high transaction costs.

However, having surplus unproductive assets often brings about inefficiency in asset portfolio; utilizing households' limited resources in unproductive assets costs potential income generating opportunities otherwise they could gain by utilizing their resource in a more profitable way. On the other hand, in time of severe droughts, the livestock to cereal terms of trade often decreases harshly, and so households are forced to deplete more livestock assets to get necessary food supply than they do during normal time. Jalan & Ravallion (2001) found an inverted U relationship between permanent income and the proportion of unproductive liquid asset to total wealth i.e. the poorest simply do not have enough wealth to be spared for liquid assets, and the richest have more productive assets proportionately to their unproductive liquid and destock productive assets in the case of negative income shocks. Comparing relative impact of rainfall shocks on different types of livestock, Fafchamps et al. (1998) found that small livestock were more favourably sold during the time of famine in Burkina Faso in the 1980s. Mogues (2011) found similar outcomes in the case of drought in Ethiopia where grain stock and aggregate livestock were more de-accumulated than cattle. Cattle are essential draught animals for farmers, and thus farm households will hold on to their cattle to avoid that they lose the essential level of draught animals for ploughing.

Both below- and above-normal rainfall shocks are often treated as one category of aggregate shock influencing a large proportion of affected villages, though household coping mechanism may differ due to the difference in duration and the scale of the disaster. To my knowledge, very few papers investigate the differences in impacts of droughts and floods. Kurosaki (2015b) used the panel data of rural Pakistan and compared the impact of floods and droughts on consumption growth, and found that household consumption was more responsive to floods than it was to droughts in rural Pakistan. Inspired by Kurosaki (2015b), I extended his work on the context of Ethiopia and investigate the accumulation path of livestock assets of the asset poor and the asset rich during the time of large rainfall fluctuation.

In addition to the use of Ethiopian data, I controlled severity of rainfall shocks by using detailed rainfall data. The previous study used a damage scale evaluated by villagers as exogenous shock variables, though this kind of scale can be affected by other socioeconomic attributes correlated with livestock-holding decision making. In line with Mogues (2011) and, this paper investigates the accumulation path of different types of livestock separately for asset-poor and asset-rich households in Ethiopia using panel data collected in time of large fluctuation of rainfalls.

3. Rural Ethiopia Setting

Ethiopia has the largest number of livestock in Africa. Ethiopian topography is divided into lowland and highland by altitude. In the lowlands, pastoralists and agro-pastoralists live mainly on livestock rearing, while farmers in the highlands conduct crop-livestock mixed farming. Since pastoralists mainly survive on livestock, they have large herding[3]. On the other hand, average sedentary farm households in the highlands have more moderate number of livestock: two oxen, a cow, a few sheep, a donkey and some chickens (Guido Gryseels & Anderson, 1983)(FAO 1996). Given this distinguishing feature between these two types of livelihood, we would not be able to study both different livelihoods without losing consistency. Thus, this study focuses on rural households who live in non-pastoral regions.

Among the animals, oxen are essential draught power for land preparation in rural Ethiopia. A pair of oxen is often used for land cultivation using a local plough called *maresha*. Studies of the International Livestock Centre for Africa (ILCA), former the International Livestock Research Institute (ILRI) found the lack of draught power induces early ploughing, less cultivated land, and less cereal cropping (Astatke & Saleem, 1993). To supplement draught animals, a usual arrangement taken by households without enough cattle is to borrow (*mekanajo*) or rent (*minda*) oxen[4] from other households in exchange for labour or grain (G. Gryseels, Astatke, Anderson, & Assemenew, 1984). However, these arrangements do not fully substitute ox draught power, forcing the households without

[3] It is estimated that they require 4.5 Tropical Livestock Units (TLUs) per capita to survive while herding (McPeak & Barrett, 2001).

[44] In Oromo region, a household with only one ox borrows another ox from another household with only one ox without any charge, though a household without any ox has to rent oxen from other households in exchange for the half of their harvest to the rentier.

enough draught power cultivate smaller plots of land than the other households. This agricultural practice heavily relying on cattle draught power provides a ‘threshold’ in the vicinity of which the households are reluctant to sell out their limited livestock resources. Hence, I will utilize the possession of more than two cattle as a proxy for the asset poverty threshold , and this treatment is also seen in Hoddinott (2006) and Miura, Kanno, & Sakurai (2012).

In Ethiopia, all land is owned by the state and is allocated to each farmer through peasant associations. Land use right is only allowed to the residents of the locality, and people who leave the locality for a long time lose their right (USAID, 2011). The short-term land lease is allowed only between local farm households, and the land rights are not allowed to be used as collateral. This restrictive land regulation inhibits privatization of land as well as migration since migrants find it difficult to acquire land (Kwak & Smith, 2013) and retain their land use right in their homelands (USAID, 2011). In Ethiopia, rural access to financial institutions is still limited. In this environment, many households rely on livestock for their wealth accumulation[5].

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5 Both post-planting and post-harvest data are available in ESS. This study uses post-planting land size data to control farm land size. Harvested land may be smaller than planted land for idiosyncratic agricultural shocks (e.g., crop disease) and might not reflect the actual size of land owned by households.

4. Data and Methods

The Ethiopian Socioeconomic Survey (ESS) was implemented during 2011's drought period and 2013 as a part of the World Bank Living Standards Measurement Studies. The first ESS was conducted in 290 rural and 43 small town enumeration areas (EAs) covering all regional states except for the capital, Addis Ababa, though the second wave of the ESS was expanded to include urban areas. The first and second waves collected information on 3,969 households and 5,262 households respectively. Among 3,969 households, wave two successfully re-interviewed 3,776 households with 5 per cent attrition rate. The data are representative at the national level, and this study only focuses on rural samples. From the total balanced rural panel, I exclude the observations from two pastoral regions, Afar and Somalie where the ox-plough production system is not prevalent. Observations with missing data for any of the variables described below were dropped from the analysis which left the balanced panel of 1,381 households. Among them, 96.32 per cent households are crop-and-livestock farmers, who conduct livestock-raising and cropping.

The sampling was conducted by a stratified two-stage design where the regions of Ethiopia serve as the strata. From each region, the primary sampling unit, Enumeration Areas (EAs) were selected based on probability proportional to the size of the total population in each region. For each rural EA, ten households were randomly selected from farm households, and another two households were randomly selected from all the other households who were not engaged in farming in the same EA. When there are no households who did not engage in farming work, additional two farm households are selected for replacement. In small town EAs, 12 households are randomly selected without stratification. Each wave of survey contains recall questions on livestock flows from the previous year, from which the level of livestock holdings in the previous years (i.e., 2010 for 2011 round and 2012 for 2013 round) can be obtained.

Rainfall data were constructed from decadal (10-day) rainfall estimates of the U.S. National Oceanic and Atmospheric Administration - NOAA[6]. NOAA has been a provider of climate information for Ethiopian Early Warning System since 1991, and from their website we can obtain images of 10-day total rainfall estimates with the accuracy of 8 km by 8 km pixel size from 1900 up to now. Using EA level latitudes and longitudes[7], I extracted EA level 10-day total rainfall from the images and added these data to calculate annual rainfall for 2010, 2011, 2012 and 2013. Unlike conventional rainfall data obtained at the nearest rain stations, EA level satellite rainfall data can minimize the measurement errors arising from the geographical distances between the stations and the EAs. I used two measurements of rainfall

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[6] The data that support the findings of this study are openly available in USGS FEWS NET Data Portal at https://earlywarning.usgs.gov/fews/product/119.

[7] To maintain confidentiality, the ESS adds some errors to EA level coordinate. For instance, small town EA level coordinates contain 0-2 km of errors and rural EA level coordinates contain 0-5 km of errors. Those errors are limited at the zone level, so that the modified coordinates still fall within the correct zones, allowing the user to obtain zone-level locational information.

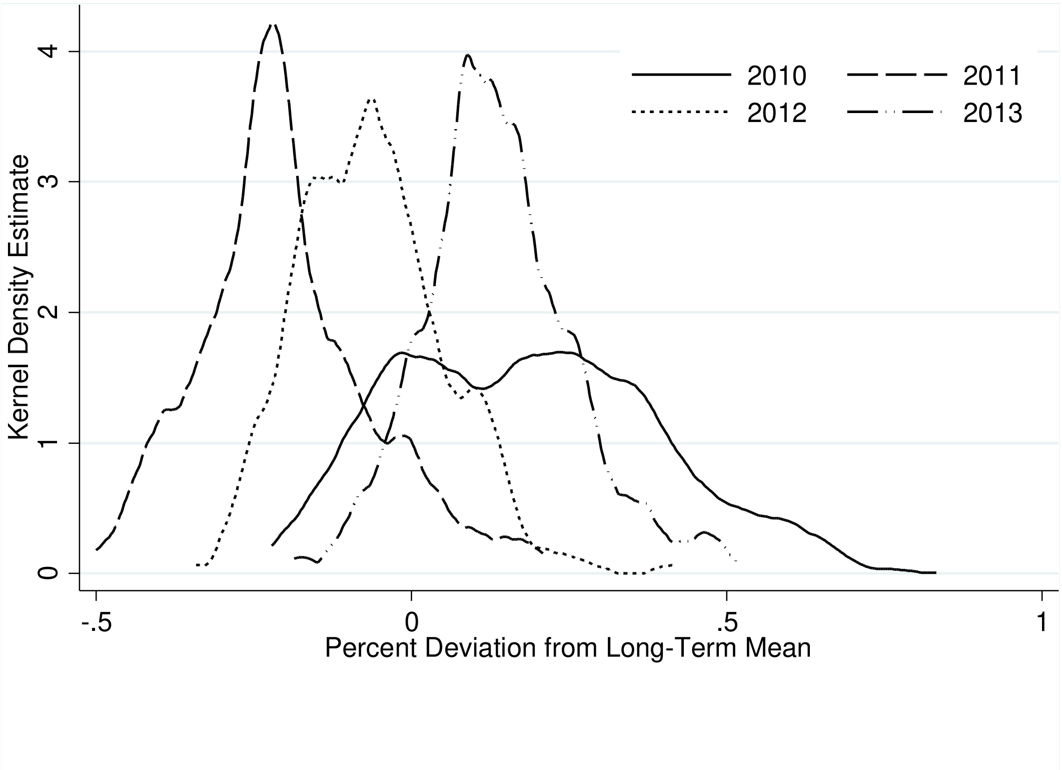
shocks: percent deviations from long-term mean annual rainfall and positive and negative percent deviation from the long-term mean. Rainfall percent deviation[8] is measured by the annual rainfall divided by the mean annual rainfall from 2000-2010 minus one, i.e. (rainfall/mean)−1. Positive and negative rainfall shocks were distinguished following Fafchamps et al. (1998) and Hoddinott (2006).

Figure 1 presents kernel density distributions of 2010-2013 annual rainfall percent deviation of the studied EA of non-pastoral regions. Ethiopia has faced recurrent floods and droughts from 2010 to 2013, and almost every year experiences unusual rainfall patterns except for 2012. The year 2009 was the second driest year on record occurring since 1971, though 2010 witnessed heavy above-normal rainfalls which induced flash and floods in five regions (Afar, Amhara, Gambella, Oromia, and Tigray) due to La Niña episodes (UNOCHA, 2016). 2011 observed below-normal rainfall at the hike of drought. Then, 2013 observed above-normal rainfalls which eventually caused the floods affecting a large part of the Somali region and two districts of Oromia region in May affecting a total of 32,391 people (UNOCHA, 2013). As the dashed distribution curve in Figure 1 is mostly to the left of zero, about 93 per cent of non-pastoral households experienced below-normal total rainfall in 2011. On the other hand, 79 per cent of the households experienced above-normal total

[8] Both absolute and percent deviation are widely utilized rainfall measurements. I explored estimates with both specifications and found no difference.

rainfall in 2013. On average, the sample households experienced 115.55 per cent more rainfall than the ten year's mean in 2013. These suggest that 2011 and 2013 witnessed two extremely different rainfall events, one with under-precipitation and the other with over-precipitation.

Figure 1. Kernel density distribution of rainfall deviation in highland Ethiopia



To examine livestock accumulation path over the survey periods across different asset-holding levels, I plotted mean and median livestock holdings in TLUs[9] over survey

[9] Total aggregate livestock holdings have been aggregated using Tropical Livestock Units (TLUs). TLU weights are calculated by typical livestock weight and their calorie consumption per unit of time. Following conversion factors for Ethiopia used by Mogues (2011), I weigh a camel as 1.43

periods by two subsamples of the asset poor and the asset rich whose asset statuses are determined by the 2010's cattle holdings (Figure 2). As we can observe in the figure, the asset poor with less than two cattle at 2010 accumulated their total livestock holdings over time and had over 3 TLUs by 2013. In contrast, the asset rich de-accumulated their livestock over time. Both asset-rich and asset-poor households increased or reduced TLUs drastically during 2011-2012 span. Since the effect of drought on household welfare has time-lag, the affected households are most likely to cope with the shocks during the hunger seasons from late 2011 to early 2012[10], consistent with the de-accumulation/ accumulation dynamics observed in Figure 2. I plotted mean and median small livestock holdings in TLUs over survey periods by two subsamples of the asset poor and the asset rich in Figure 3. Wider variances exist in small livestock holdings than total livestock holdings, though medians of small livestock holdings have similar dynamic paths to those of total livestock holdings.

TLU, a cattle as 1 TLU, a horse, a mule and a donkey as 0.5 TLU, a goat and sheep as 0.1 TLU, and a chicken as 0.05 TLU.

[10] Livestock holding data was collected during November to December in 2011 and 2013. As planting relies on subsequent rainy seasons, the consequence of failure of *meher* rain (June-September 2010) and *belg* rain (February-May 2011) were observed in the next harvest and eventually affect household welfare in next hunger seasons from late-half of 2011 (June-Sept) in *meher* rain zone to early 2012 (April-June) in *belg* rain zone.

Figure 2. Mean and median aggregate livestock holding (TLU) by asset-status

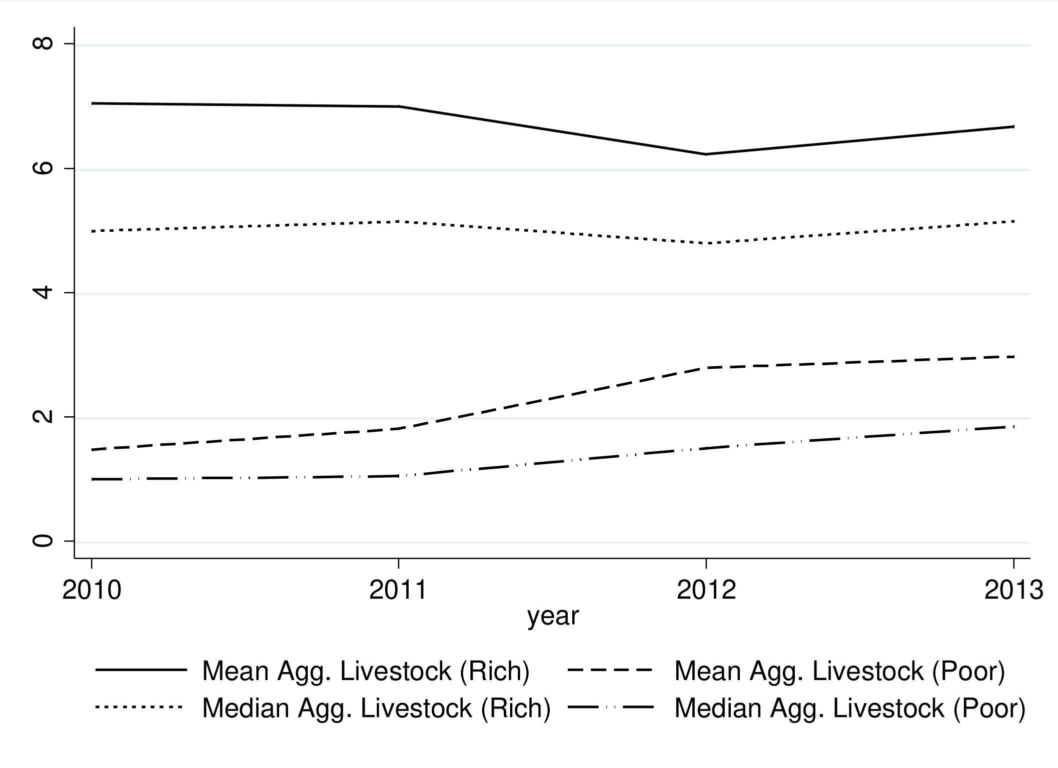
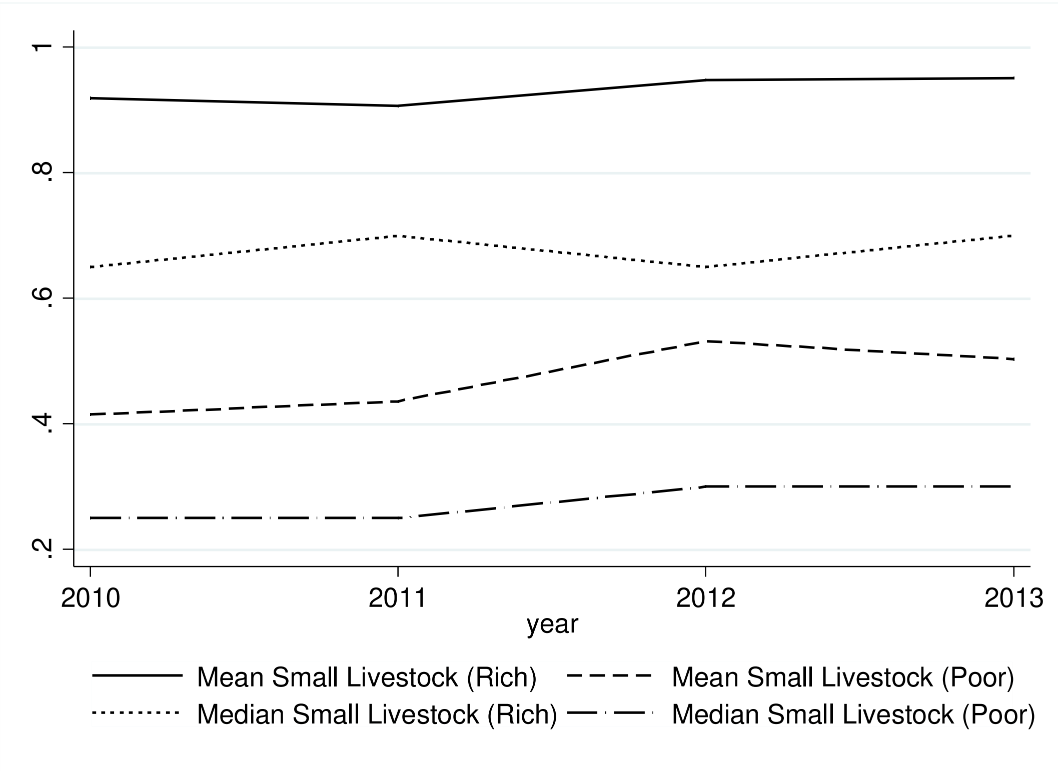


Figure 3. Mean and median small-livestock holding (TLU) by asset-status



To investigate the effect of current livestock holdings on future holdings before imposing parametric assumption, I ran a nonparametric regression where the independent variable is household i's livestock holdings at the t-s period (y_{it-s}), and the dependent variable is livestock holdings at t period (y_{it}). Figure 4 shows the result of a locally weighted scatterplot smoothing estimator (LOWESS) of aggregate livestock holdings in TLUs for households who live in rural areas of the studied regions, where t = 2011, 2012, and 2013 and s = 1. The thick solid, dashed, and thin solid curves represent the annual evolution of livestock holdings at the different points in time. For each time gap, curves intersect the 45-degree line only at once, and the households whose livestock holdings are below the intersection have positive wealth accumulation, while the households whose livestock holdings are above the intersection gradually reduce their livestock assets over time, approaching to the single equilibrium level. The most severe asset de-accumulation among the households with above-intersection livestock holdings occurred from 2011 to 2012 right after the drought. The observed pattern reflects convergence trends. The growth rate of livestock accumulation is higher for asset-poor households improving livestock-holding inequality, consistent with the observation of Van Campenhout & Dercon (2012) on the survey from 1993 to 2004.

Figure 5 is the result of LOWESS estimation on small livestock holdings for crop-and-livestock farmers. Similar to aggregate livestock, small livestock were also the most de-accumulated during 2011 to 2012 and showed a convergence trend. Comparing Figure 4 and

5, I found that small livestock holdings have slightly flatter curves than aggregate livestock, which suggests that small livestock are accumulated a little faster than aggregate livestock holdings.

If we closely look at the convergence points, the estimated intersection points vary for different time spans. For example, during 2010-2011 the intersection lies around 6.75-80, though the convergence point declines to 3.90-94 for the period 2011-2012 and rises again to 9.9-10.04 for 2012-2013. These discrepancies of “convergence” points among different time spans are likely to be explained by shocks experienced in different locations at each point of time and household-level heterogeneity which induces different reactions against these shocks. Due to household heterogeneity, there is a situation where particular groups of people cope with adverse shocks more easily while other groups do not. This is illustrated in Figure 6, where I plot livestock dynamics for three hypothetical groups of households. Three lines in Figure 6 show the situations where there is a single stable equilibrium at the intersection with the 45-degree line. Where μ_i represents household heterogeneity, the solid line depicts livestock dynamic for the average household ($\mu_i = 0$), and the other two depict those for the households with favorable ($\mu_i = \bar{\mu}$) and less favorable heterogeneity($\mu_i = \underline{\mu}$) for coping with adverse shocks. Due to such household heterogeneity, those households may be able to expand or lose their livestock holdings much faster than the average one. In addition, both rainfall variation over time and across locations are high in our sample. Hence, we need to account for both household heterogeneity and location-specific shocks to explore the dynamic livestock accumulation.

Figure 4. Nonparametric estimation of dynamic livestock asset path (Livestock)

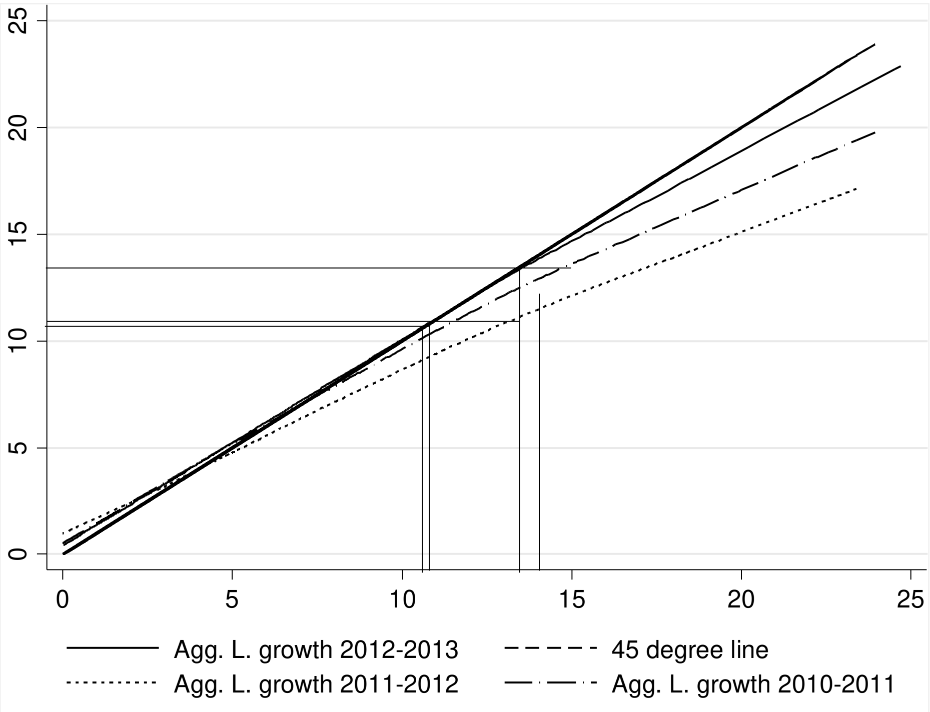


Figure 5. Nonparametric estimation of dynamic livestock asset path (Small livestock)

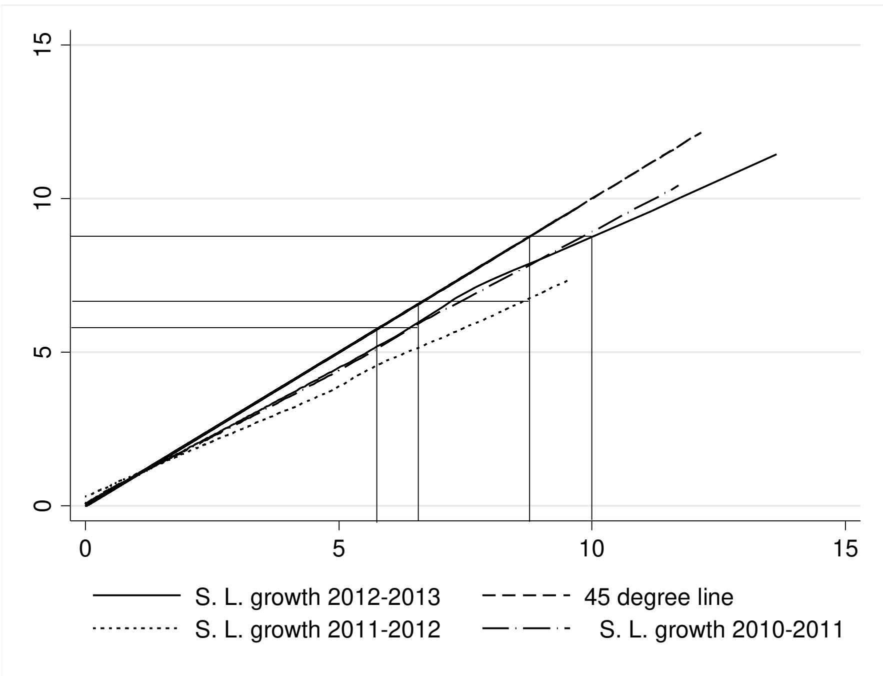
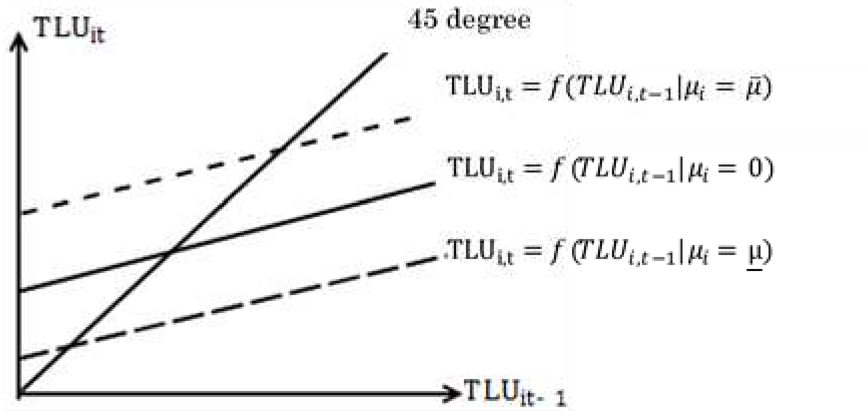


Figure 6. Differences in convergence



In Table 2, I presented summary statistics on shocks, mitigating factors and demographic variables of surveyed households by the asset statuses determined by initial livestock holdings. I divided sampled households into 1,068 asset-rich households and 313 asset-poor households. Possession of more than two cattle is considered essential for ploughing in Ethiopia and also considered as a critical asset thresholds in other Sub-Sahara African countries (Hoddinott, 2006; Miura et al., 2012). Average asset-poor households planted significantly smaller size of land compared to that of asset-rich households, probably reflecting their limited draught power available for ploughing, consistent with the study of Astatke & Saleem (1993). Asset-rich households tend to have larger household size, though they have slightly smaller dependency ratio11. Mean percent deviation from mean long-term annual rainfall in 2011 was almost the same over different asset statuses, though the asset rich

[11] Dependency ratio is calculated as the ratio of dependent household members (people younger than 15 or older than 64 years old) to the working-age members whose age are between 15 and 64 years old.

had significantly more rainfall in 2013. Shock-mitigating factors such as access to loan, amounts of private transfers (i.e., gift, money transfer) and public transfer (i.e., money, in-kind, or food transferred from government, NGOs or international organizations) have no difference between the asset poor and the asset rich. Nevertheless, another important mitigating factor, engagement in a non-farm activity is observed more often in asset-poor households. This suggests two contradictory scenarios: the households who diversified their income source into non-farm economic activities might not need to self-insure themselves since nonfarm activities are more durable to natural shocks, or the households without draught power cannot earn enough harvest from their fields and engage in unprofitable petty trading. Though the mechanism behind larger non-farm enterprise engagement of the asset poor is important, small observations on nonfarm income questionnaire made it difficult to differentiate those two possible scenarios. Also, later estimations on livestock holdings have insignificant coefficients of nonfarm enterprise engagement, indicating non-farm enterprise engagement do not associate with the livestock-holding dynamic after controlling various household characteristics.

Table 2. Characteristics of the asset poor and the asset rich

	obs of asset-poor	mean in asset-poor	obs of asset-rich	mean in asset-rich	mean difference	t-stat
TLU_t	313	2.074	1068	5.948	-3.874***	(-13.84)
TLU_t-1	313	1.951	1068	5.618	-3.667***	(-13.30)
TLU_t-2	313	1.472	1068	5.872	-4.400***	(-21.20)
TLU_t-3	313	0.965	1068	5.739	-4.774***	(-23.29)
cattle_t	313	1.549521	1068	4.926966	-3.377***	(-13.29)
cattle_t-1	313	1.376997	1068	4.617978	-3.241***	(-12.88)
cattle_t-2	313	0.9616613	1068	4.960674	-3.999***	(-22.05)
cattle_t-3	313	0.485623	1068	4.820225	-4.335***	(-23.93)
Percent deviation from historical annual rainfall mean	313	0.098	1068	0.124	-0.026***	(-2.61)
Percent deviation from historical annual rainfall mean_t-2	313	-0.230	1068	-0.230	0.000	(0.04)
Household size	313	4.955	1068	5.908	-0.953***	(-7.52)
Household size_t-2	313	5.045	1068	5.976	-0.931***	(-7.48)
Dependency ratio	313	130.293	1068	127.757	2.536	(0.42)
Dependency ratio_t-2	313	143.855	1068	130.337	13.52**	(2.33)
Private transfer (in thousand ETB)	313	0.255	1068	0.378	-0.123	(-0.86)
Private transfer_t-2 (in thousand ETB)	313	0.178	1068	0.230	-0.0526	(-0.66)
Proportion of villagers who receive public transfer except for HH_i	313	0.116	1068	0.100	0.0155	(1.22)
Proportion of villagers who receive public transfer except for HH_i in t-2	313	0.147	1068	0.132	0.0151	(0.98)
Nonfarm enterprise (0/1)_t	313	0.361	1068	0.270	0.0914***	(3.14)
Nonfarm enterprise (0/1)_t-2	313	0.297	1068	0.198	0.0996***	(3.75)
Planted land size (ha)	313	1.036	1068	1.834	-0.797***	(-3.32)
Planted land size_t-2 (ha)	313	0.668	1068	1.742	-1.074***	(-7.16)
Proportion of certified land	313	0.474	1068	0.590	-0.116***	(-3.99)
Proportion of certified land_t-2	313	0.426	1068	0.510	-0.0847***	(-2.85)
Loan (0/1)	313	0.444	1068	0.405	0.0387	(0.97)
Loan_t-2 (0/1)	313	0.383	1068	0.350	0.0332	(0.94)
Vaccinated animal (TLU)	313	0.529	1068	1.853	-1.324***	(-7.48)
Vaccinated animal_t-2 (TLU)	313	0.310	1068	1.576	-1.266***	(-7.92)
Irrigation (0/1)	313	0.083	1068	0.098	-0.0152	(-0.81)
Irrigation_t-2 (0/1)	313	0.080	1068	0.117	-0.0372*	(-1.86)
Fertilizer use (0/1)	313	0.853	1068	0.897	-0.0440**	(-2.16)
Fertilizer use_t-2 (0/1)	313	0.783	1068	0.875	-0.0918***	(-4.06)

*Significant at the 10% level. **Significant at the 5% level. *** Significant at the 1% level.

The extent of livestock-holding growth from 2010 to 2013 differs among the different asset level. Though asset-rich households experienced small growth (4%) in three years, asset-poor households experienced large positive asset growth (115%) from the before-drought (2010) to the after-drought period (2013). In sum, we can see convergence trends in livestock accumulation over time again in descriptive statistics. Among this growth in livestock holdings, cattle holdings were the most increased among the surveyed households. Mean cattle holdings of the asset poor increased from 0.48 TLU in 2010 (49% of total livestock holdings) to 1.55 TLU in 2013 (69% of total livestock holdings). On the other hand, cattle holdings of the asset rich had barely changed: 4.82 TLU (83%) in 2010 to 4.93 TLU (82%) in 2013. Cattle constitute a major proportion of livestock holdings, reflecting the relative importance of cattle as a draught animal.

5. Empirical strategy

The non-parametric regressions on Figure 4 and 5 only explain the bivariate relations between current and past livestock holdings without controlling the effects of rainfall, demographic and socioeconomic variables. Drawing upon the empirical strategies used by Kurosaki (2015a) and Mogues (2011), I start from standard dynamic panel data model like below

$$TLU_{i,t} = \beta_0 + TLU_{i,t-1}\beta_1 + \boldsymbol{X}'_{i,t}\beta_2 + \boldsymbol{M}'_{i,t}\beta_3 + Z_{i,t}A_i\beta_4 + Z_{i,t}\beta_5 + \epsilon_{i,t} \quad (1)$$

$$\epsilon_{i,t} = \mu_i + v_{i,t}$$

where μ_i is time-invariant unobservable household factors and $v_{i,t}$ is a white noise error term. $TLU_{i,t}$ is the amount of livestock that household *i* holds in time *t*. Previous year's livestock-holding level, $TLU_{i,t-1}$ is included following conventional growth model. The variable $Z_{i,t}$ represents rainfall measurements defined above. Asset status A_i is a binary dummy which takes one if the household had more than two cattle in 2010 (i.e., the asset rich), otherwise zero. To investigate how rainfall shocks influence livestock holdings among the asset rich and the asset poor, the interactions of rainfall shocks and initial asset status are included. $\boldsymbol{X}'_{i,t}$ is a vector of demographic and socioeconomic characteristics of household *i* at point *t*, and $\boldsymbol{M}'_{i,t}$ is a vector of mediating factors of household *i* at point *t*: levels of private transfer, the proportion of villagers receiving public transfers excluding the household i[12], dummy for whether the household engaged in a nonfarm enterprise, and a dummy for access to loan. Household characteristics such as household size and dependency ratio are included in $\boldsymbol{X}'_{i,t}$ to control life-cycle effects. The other variables in $\boldsymbol{X}'_{i,t}$ include cultivated land size (ha), the proportion of certified land, irrigation use and the number of vaccinated livestock since the impact of rainfall shocks might vary among different land sizes and the availability of pasture and irrigation. Access to irrigation facilities will alleviate crop damage from drought. As weaken livestock is vulnerable to infectious disease during drought time, vaccination matters to prevent animal loss from infectious disease. Faced with the rise of land conflict due to land scarcity, each regional government has implemented land certification for agricultural land since the early 2000s. The impact of land certification on livestock herding is not yet clear, but we can anticipate privatization of common land can affect the availability of pasture for livestock herding and negatively affect livestock holdings.

[12] The number of households who received aid during the last 12 months excluding the household *i* divided by the number of households in village minus one.

The main concern of this paper is parameters β_4 and β_5 which show the average impact of rainfall shocks on the household livestock growth of each asset group. The parameter β_4 indicates whether asset-rich households face larger or smaller declines in livestock holdings compared to asset-poor households if their EAs are hit by rainfall shocks.[13] If asset-rich households de-accumulate more their livestock in the face of negative rainfall shocks, i.e. percent deviation ($Z_{i,t}$) takes a negative value, I expect $\beta_4 > 0$. The parameter $0 < \beta_1 < 1$ shows a conditional convergent trend in livestock accumulation, though $\beta_1 > 1$ suggests a divergence trend. Following Jones (2002), I use the term "conditional convergence" here since each household is likely to have a different steady state due to the heterogeneity of household characteristics.

Time-invariant household heterogeneity (μ_i) is most likely to affect both current and lagged livestock holdings and causes the omitted variable bias. Possible time-invariant household heterogeneity which affects the accumulation of livestock holdings is characteristics of hard work and diligence of household members. To handle the unobserved time-invariant heterogeneity, common procedure of dynamic panel model with fixed T starts with the first different transformation. Instead, I took the two-period difference of equation

[13] The interaction terms of initial attribute and aggregate shocks are often utilized in macroeconomic analysis on the impact of natural disasters on economic growth as in Noy, (2009). Application to microeconomic analysis is seen in Kurosaki (2015b).

(1), because the vectors of $\boldsymbol{X'}_{i,t}$ and $\boldsymbol{M'}_{i,t}$ are available only for t and $t-2$ periods. This can be expressed as:

$$TLU_{i,t} - TLU_{i,t-2} \qquad (2)$$
$$= (TLU_{i,t-1} - TLU_{i,t-3})\beta_1 + (\boldsymbol{X'_{i,t}} - \boldsymbol{X'}_{\boldsymbol{i,t-2}})\beta_2 + (\boldsymbol{M'_{i,t}}$$
$$- \boldsymbol{M'_{i,t-2}})\beta_3 + (Z_{i,t}A_i - Z_{i,t-2}A_i)\beta_4 + (Z_{i,t} - Z_{i,t-2})\beta_5$$
$$+ (v_{i,t} - v_{i,t-2})$$

where time-invariant heterogeneity (μ_i) and constant term (β_0) are removed after a difference transformation. However, there is still a possibility that two-period difference of $TLU_{i,t-1}$ is correlated to the two-period difference of error term $v_{i,t}$. This problem is entailed with dynamic panel data models and called Nickell bias. Anderson & Hsiao (1981) proposed the use of an instrument for lagged dependent variable. In our model, TLU_{t-3} or the first difference of $TLU_{i,t-3}$ can be used as an instrument because they have a strong correlation with $(TLU_{i,t-1} - TLU_{i,t-3})$ while displaying no correlation with $(v_{i,t} - v_{i,t-2})$. Arellano's (1989) numerical analysis compared the possible two instruments and found the estimator using the level instrument has smaller asymptotic standard errors with fixed T sample. Accordingly, I used $TLU_{i,t-3}$ as an instrument.

Table 3 presents the results of estimations of the model (1). The lagged livestock holdings on the right-hand side are treated as an endogenous variable and are instrumented by the Anderson-Hsiao instrument variable (i.e., $TLU_{i,t-3}$). Agricultural variables such as access to irrigation, fertilizer use, and vaccination practices are controlled to condition the resilience of agricultural practice. Rainfall shock and its interaction with asset status have their expected positive signs on aggregate livestock holdings, though they are not significant. On the other hand, the asset status interaction terms are positive and significant on small livestock holdings, suggesting that the asset rich more often destock small livestock in the face of negative rainfall shocks than the asset poor. The size of land has a positive and significant effect on aggregate livestock, though the land size is not significant for small livestock. The loan access variable has significantly negative coefficients on small livestock holdings: households with access to loan institutions might have better abilities in intertemporal resource allocation, and may have low precautionary demand for livestock. The result of heteroscedasticity test (Pagan Hall general test) suggests the presence of heteroscedasticity in the estimations of small livestock holdings, and thus I present heteroscedasticity-robust statistics for small livestock estimations. The weak identification tests under homoscedasticity and heteroscedasticity assumptions confirm the instrument relevance between the dependent variable and the lagged dependent variables. The coefficients of the lagged dependent variable lying between zero and one confirms the conditional convergence consistent with the results from LOWESS.

Table 3. Anderson-Hsiao estimates of aggregate-livestock and small livestock holdings with rainfall

	TLU		Small animal	
	(1)	(2)	(3)	(4)
TLU_(t-1)	0.504***	0.504***	0.483***	0.484***
	(0.089)	(0.089)	(0.096)	(0.095)
Rainfall shock*Asset status at t-3	0.177	0.177	0.218**	0.233***
	(0.443)	(0.443)	(0.087)	(0.089)
Rainfall shock, % deviation from 10	0.030	0.030	-0.120	-0.172**
yr annual rainfall mean	(0.402)	(0.411)	(0.074)	(0.081)
Squared rainfall shock		0.009		-0.621*
		(1.135)		(0.350)
Household size	0.021	0.021	0.025*	0.023*
	(0.050)	(0.051)	(0.014)	(0.014)
Dependency ratio	0.001	0.001	-0.000	-0.000*
	(0.001)	(0.001)	(0.000)	(0.000)
Private transfer (thousand ETB)	0.015	0.015	-0.004	-0.004
	(0.027)	(0.027)	(0.007)	(0.007)
Nonfarm enterprise (0/1)	0.200	0.200	0.043	0.037
	(0.187)	(0.187)	(0.048)	(0.048)
Planted land size (ha)	0.034**	0.034**	0.002	0.002
	(0.015)	(0.015)	(0.002)	(0.002)
Proportion of certified land	0.083	0.083	-0.017	-0.020
	(0.143)	(0.143)	(0.034)	(0.034)
Loan (0/1)	-0.081	-0.081	-0.050**	-0.048**
	(0.087)	(0.087)	(0.022)	(0.021)
Proportion of villagers who receive	-0.180	-0.180	-0.059	-0.051
public transfer except for HH_i	(0.246)	(0.246)	(0.071)	(0.070)
Irrigation (0/1)	0.105	0.105	-0.094*	-0.093*
	(0.182)	(0.182)	(0.050)	(0.050)
Fertilizer use (0/1)	0.166	0.166	0.072*	0.074*
	(0.159)	(0.159)	(0.040)	(0.040)
Vaccinated animal (TLU)	0.065***	0.065***	0.003	0.003
	(0.021)	(0.021)	(0.006)	(0.006)
Underidentification test				
Anderson canon. Corr LM stat	47.987	48.225	N/A	N/A

Notes:
1.Non-robust SE in parentheses in (1) & (2). Robust SE in parentheses in (3) & (4).
2.*Significant at the 10 per cent level, ** significant at the 5 per cent level, *** significant at the
3. Sample are drawn from Tigray, Amhara, Oromia, SNNP regions.

Table 4. Anderson-Hsiao estimates of aggregate-livestock and small livestock holdings with rainfall (with positive and negative rainfall shock)

	TLU			small animal		
	(1)	(2)	(3)	(4)	(5)	(6)
TLU_(t-1)	0.491***	0.514***	0.498***	0.461***	0.486***	0.477***
	(0.077)	(0.090)	(0.084)	(0.098)	(0.095)	(0.097)
Negative rainfall shock*Asset		-0.425			-0.418***	
status at t-3		(0.726)			(0.141)	
Negative rainfall shock	-0.363	-0.031	-0.364	-0.266**	0.0563	-0.271**
	(0.420)	(0.706)	(0.418)	(0.132)	(0.134)	(0.131)
Positive rainfall shock*Asset			0.198			0.388*
status at t-3			(0.952)			(0.215)
Positive rainfall shock	-0.079	-0.102	-0.246	-0.226	-0.246	-0.553**
	(0.547)	(0.541)	(0.969)	(0.153)	(0.153)	(0.246)
Household size	0.019	0.017	0.019	0.024*	0.022	0.023*
	(0.051)	(0.050)	(0.051)	(0.014)	(0.014)	(0.014)
Dependency ratio	0.001	0.001	0.001	-0.000	-0.000*	-0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Private transfer (thousand	0.015	0.014	0.015	-0.004	-0.004	-0.004
ETB)	(0.027)	(0.026)	(0.027)	(0.007)	(0.007)	(0.007)
Nonfarm enterprise (0/1)	0.191	0.193	0.192	0.037	0.035	0.036
	(0.189)	(0.186)	(0.188)	(0.049)	(0.048)	(0.049)
Planted land size (ha)	0.033**	0.034**	0.033**	0.002	0.002	0.002
	(0.015)	(0.015)	(0.015)	(0.003)	(0.002)	(0.002)
Proportion of certified land	0.080	0.082	0.080	-0.019	-0.020	-0.021
	(0.144)	(0.142)	(0.144)	(0.034)	(0.034)	(0.034)
Loan (0/1)	-0.082	-0.078	-0.081	-0.049**	-0.049**	-0.049**
	(0.087)	(0.087)	(0.087)	(0.022)	(0.021)	(0.022)
Proportion of villagers who	-0.168	-0.180	-0.171	-0.048	-0.055	-0.051
receive public transfer except	(0.247)	(0.244)	(0.246)	(0.071)	(0.070)	(0.070)
Irrigation (0/1)	0.108	0.105	0.106	-0.093*	-0.091*	-0.094*
	(0.183)	(0.181)	(0.183)	(0.051)	(0.050)	(0.050)
Fertilizer use (0/1)	0.169	0.164	0.168	0.070*	0.073*	0.071*
	(0.160)	(0.158)	(0.160)	(0.040)	(0.040)	(0.040)
Vaccinated animal (TLU)	0.067***	0.064***	0.066***	0.004	0.003	0.003
	(0.021)	(0.021)	(0.021)	(0.006)	(0.006)	(0.006)
N	1381	1381	1381	1377	1377	1377
adj. R-sq	0.564	0.576	0.567	0.392	0.401	0.397

Notes:
1.Non-robust SE in parentheses in (1), (2) & (3). Robust SE in parentheses in (3) & (4).
2.*Significant at the 10 per cent level, ** significant at the 5 per cent level, *** significant at the 1 per cent level.
3. Sample are drawn from Tigray, Amhara, Oromia, SNNP regions.

I separated the rainfall shocks into positive (above-normal) and negative (below-normal) rainfall shocks[14] and estimates those effects on livestock-holdings on table 4. Negative and positive rainfalls are strongly correlated to each other by definition, and thus the model containing both rainfall variables suffer from multicollinearity. In view of this difficulty, I limit one interaction term of either positive or negative rainfall in an estimation. Both negative and positive rainfall shocks have negative coefficients on aggregate and small livestock holdings, though only negative rainfall shock has significant effect on small livestock holdings.

Table 4 Column (5) suggests that the asset rich decrease their small livestock more than the asset poor do when they face a negative rainfall shock. This effect is significant at 1 per cent level and suggests that asset-rich households would decrease by 0.05 TLU for small livestock if they have the average rainfall of 2011. The column (3) and (6) estimated the effect of above-normal rainfall shocks on livestock holdings. Above-normal rainfall shocks do not have heterogeneous significant effects on aggregate livestock holdings among the asset rich and the asset poor (Column 3), though it has negative and significant heterogenous

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[14] Positive rainfall shock takes $\frac{\text{(Annual rainfall)}}{\text{long−term annual rainfall mean}} - 1$, when $Annual\ rainfall > long\ term\ annual$ and 0 otherwise. Negative rainfall shock takes $\left|\frac{\text{(Annual rainfall)}}{\text{long−term annual rainfall mean}} - 1\right|$ and 0 other wise.

effect on small livestock holdings (Column 6). The extent of above-normal rainfall is stronger for the asset poor's small livestock holdings.

The mechanism behind the opposite direction of behaviours among asset-rich and asset-poor households against below- and above-normal rainfall is unclear. The potential reasons are two: households with a large amount of livestock cannot secure enough feed for their livestock and fail in maintaining their livestock herd during a drought. Or the asset rich chose to sell their livestock to protect their consumption. During the heavy drought time, serious outbreaks of infectious diseases among livestock are widely observed, and the first potential reason is highly possible. Hence, we need to carefully investigate whether a declining livestock holdings of the asset rich is a part of household coping strategy or a mere result of droughts.

6. Effects of rainfall on net sale

To investigate the mechanism behind these bifurcated asset-accumulation dynamics, I examine a flow variable of livestock accumulation, net-sale (i.e., sold TLU - purchased TLU) in this section. Since transactions of livestock, especially cattle are discrete events and median net-sale is zero, I employed random effects ordered probit estimate under the assumption that the true model is nonlinear, where net sales are categorized into three groups (3 = positive net sales, 2 = zero net sales and 1 = negative net sales). The threshold parameters are statistically significantly different from each other, and thus the three categories of net sales do not need to be combined to two. The result is presented in table 5. To avoid endogeneity entailed with the lagged dependent variable, I use the death- and birth-ratio of livestock among total holdings as a replacement for lagged holdings. Death and birth of livestock are more likely to be affected by exogenous climate shocks rather than by the household fixed effect, and adding the death- and birth-ratios to the net sales estimation enables us to control direct rainfall-shock effect on livestock health. To check the model misspecification problem under the assumption of nonlinearity, I also obtain fixed effects and random effects estimators on table 6. The LM tests on the random effects versus the pooled regression are significant and support the use of random effects estimators. The robust Hausman test argues in favour of the random effects model relative to the fixed effects model only for net-sale estimates of small livestock. To conserve space, either random-effects or fixed-effects estimators supported by robust Hausman test are reported.

Table 5. Ordered Probit estimate of net sale

Dependent variable	Netsale of TLU				Netsale of small animals			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TLU_{t-1}		0.0484***		0.0550***		0.438***		0.442***
		(0.0130)		(0.0140)		(0.0410)		(0.0412)
Death ratio, dead TLU/total TLU	-0.00422		0.000358		-0.0680***		-0.0657***	
	(0.0158)		(0.0153)		(0.0202)		(0.0206)	
Birth ratio, born TLU/total TLU	0.0935**		0.0719*		0.133***		0.131***	
	(0.0443)		(0.0424)		(0.0264)		(0.0265)	
Negative rainfall shock*Asset status at t-3	2.193***	1.211***			1.046***	0.215		
	(0.307)	(0.348)			(0.345)	(0.307)		
Negative rainfall shock	-2.310***	-1.545***	-0.609***	-0.623***	-1.588***	-1.016***	-0.774***	-0.846***
	(0.309)	(0.315)	(0.210)	(0.207)	(0.350)	(0.309)	(0.227)	(0.212)
Positive rainfall shock*Asset status at t-3			0.541	-0.243			0.392	-0.397
			(0.402)	(0.398)			(0.467)	(0.403)
Positive rainfall shock	-0.0567	-0.174	-0.493	0.00705	0.173	-0.249	-0.156	0.0712
	(0.259)	(0.255)	(0.413)	(0.390)	(0.286)	(0.267)	(0.488)	(0.421)
Household size	0.0101	-0.0108	0.0176	-0.00804	0.00528	-0.0333***	0.00880	-0.0312***
	(0.0108)	(0.0124)	(0.0108)	(0.0127)	(0.0123)	(0.0119)	(0.0123)	(0.0119)
Dependency ratio	0.000200	0.000179	0.0000971	0.000122	0.000320	0.000388	0.000261	0.000379
	(0.000235)	(0.000260)	(0.000235)	(0.000271)	(0.000259)	(0.000260)	(0.000257)	(0.000260)
Private transfer (thousand ETB)	-0.0125	-0.0103	-0.0114	-0.0104	-0.00524	-0.00549	-0.00491	-0.00594
	(0.0120)	(0.0112)	(0.0116)	(0.0113)	(0.0126)	(0.0115)	(0.0123)	(0.0117)
Nonfarm enterprise (0/1)	-0.0821	-0.0319	-0.0962*	-0.0386	-0.136**	-0.0493	-0.144**	-0.0526
	(0.0511)	(0.0506)	(0.0512)	(0.0509)	(0.0565)	(0.0520)	(0.0566)	(0.0521)
Planted land size (ha)	-0.00737	-0.0136	-0.00525	-0.0129	0.00676	-0.00210	0.00788	-0.00174
	(0.00601)	(0.00831)	(0.00579)	(0.00818)	(0.00578)	(0.00732)	(0.00583)	(0.00723)
Proportion of certified land	-0.0154	-0.00830	-0.00270	0.00212	0.00191	-0.00855	0.00829	-0.00442
	(0.0460)	(0.0456)	(0.0462)	(0.0458)	(0.0514)	(0.0475)	(0.0515)	(0.0475)
Loan (0/1)	0.0298	0.0428	0.0274	0.0434	0.0750*	0.0873**	0.0744*	0.0867**
	(0.0393)	(0.0388)	(0.0394)	(0.0389)	(0.0422)	(0.0405)	(0.0422)	(0.0405)
Proportion of villagers who receive public transfer HH_i	0.512***	0.525***	0.505***	0.521***	0.434***	0.351***	0.432***	0.345***
	(0.104)	(0.104)	(0.105)	(0.104)	(0.115)	(0.112)	(0.115)	(0.112)
cut1								
_cons	-0.470***	-0.398***	-0.439***	-0.355***	-0.484***	-0.537***	-0.470***	-0.520***
	(0.0772)	(0.0790)	(0.0773)	(0.0802)	(0.0928)	(0.0825)	(0.0933)	(0.0831)
cut2								
_cons	0.333***	0.419***	0.358***	0.461***	0.578***	0.701***	0.592***	0.718***
	(0.0769)	(0.0813)	(0.0772)	(0.0833)	(0.0934)	(0.0845)	(0.0939)	(0.0853)
sigma2_u								
_cons	0.102**	0.104**	0.109**	0.109**	0.222***	0.209***	0.224***	0.209***
	(0.0433)	(0.0440)	(0.0440)	(0.0449)	(0.0571)	(0.0515)	(0.0572)	(0.0516)
sample size	3229	3295	3229	3295	2860	3291	2860	3291

Note:

1. Robust standard errors in parentheses. *Significant at the 10 per cent level, **significant at the 5 per cent level, ***significant at the 1 per cent level.

2. Sample are drawn from Tigray, Amhara, Oromia, SNNP regions.

Consistent with livestock dynamics estimate on Table 4, the interaction of asset status and below-normal rainfall deviations is positive and significant at 1 per cent level, which suggests that asset-rich households sell more livestock in the face of below-normal rainfall than asset-poor households do. Below-normal rainfall has negative effects on both aggregate and small livestock net-sales, suggesting that the asset poor purchase those livestock in the face of below-normal rainfall shock (Table 5 and Table 6). Above-normal rainfall has insignificant effect on net-sale of both aggregate and small livestock in Table 5. For the small livestock net sale estimate, this non-significant result sounds contrary to the finding of the estimates of small livestock holdings dynamics on Table 4 where above-normal rainfall has negative effects on small livestock holdings. Non-responsiveness of the small livestock net sale of asset-poor households may indicate that the deduction of small livestock holdings of asset-poor households is the result of the loss due to the disasters induced by above-normal rainfall. This is supported by negative and significant coefficients of death ratio in all the specifications of small livestock net sale in Table 5 and 6. Birth ratio has the positive and significant effect on both aggregate and small livestock net sales, suggesting that births of livestock induce the sales of livestock asset. Also, death ratio is negatively significant on net-sale of small livestock in ordered probit estimates, suggesting that deaths of small livestock decrease the sale.

Though the other coefficients on linear terms of household and village characteristics are not main focus of the paper, I comment on them briefly. Village-level mean access to public transfer (except for household *i*) has positive and significant coefficients consistently: it suggests that if other things are equal, the availability of public transfer increases net-sale of livestock. One possible reason is that villages with access to public transfer may no longer need to self-insure themselves through livestock in the face of natural disasters, though further investigations are required.

Table 6. Fixed and random effect estimate of net sale

Dependent variable	Net sale of TLU (FE)		Net sale of small animal (RE)	
	(1)	(2)	(3)	(4)
Death ratio, dead TLU/total	-0.013	-0.012	-0.015***	-0.014***
TLU	(0.038)	(0.038)	(0.004)	(0.004)
Birth ratio, born TLU/total	0.095***	0.089**	0.026***	0.026***
TLU	(0.035)	(0.035)	(0.005)	(0.005)
Negative rainfall	1.673***		0.226***	
shock*Asset status at t-3	(0.321)		(0.083)	
Negative rainfall shock	-1.482***	-0.141	-0.309***	-0.131**
	(0.304)	(0.239)	(0.078)	(0.06)
Positive rainfall		-2.007***		0.009
shock*Asset status at t-3		(0.448)		(0.108)
Positive rainfall shock	0.232	1.881***	0.035	0.028
	(0.300)	(0.470)	(0.064)	(0.114)
Household size	0.029	0.027	0.003	0.004
	(0.029)	(0.029)	(0.003)	(0.003)
Dependency ratio	0.000	-0.001	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Private transfer (thousand	-0.018	-0.019	-0.002	-0.003
ETB)	(0.016)	(0.016)	(0.003)	(0.003)
Nonfarm enterprise (0/1)	-0.191*	-0.197*	-0.037**	-0.039**
	(0.105)	(0.105)	(0.016)	(0.016)
Planted land size (ha)	-0.029***	-0.029***	0.001	0.002
	(0.007)	(0.007)	(0.001)	(0.001)
Proportion of certified land	0.028	0.034	-0.006	-0.004
	(0.076)	(0.077)	(0.013)	(0.013)
Credit (0/1)	0.012	0.012	0.007	0.007
	(0.047)	(0.047)	(0.013)	(0.013)
Proportion of villagers who	0.310**	0.297**	0.106***	0.105***
receive public transfer	(0.121)	(0.123)	(0.029)	(0.029)
_cons	0.073	0.085	0.004	-0.002
	(0.191)	(0.190)	(0.021)	(0.021)
N	3229	3229	2860	2860
Overall R-sq	0.024	0.003	0.025	0.022
Hausman test	Prob>chi2 =0.000	Prob>chi2 =0.000	Prob>chi2 =0.247	Prob>chi2 =0.397

Note:
1. Robust standard errors in parentheses. *Significant at the 10 per cent level, **significant at the 5 per cent level, ***significant at the 1 per cent level.
2. Sample are drawn from Tigray, Amhara, Oromia, SNNP regions.

7. Conclusion

Using two-year panel data of rural Ethiopia, this article discusses heterogeneity in livestock accumulation among different asset-holding levels. Analysis of livestock accumulation comparing different asset-status subsamples reveals that the effect of below- and above-normal rainfall on livestock holdings differ among initial asset statuses. The households who have enough cattle power for ploughing (i.e., the asset rich) de-accumulate their small livestock holdings in the face of a below-normal rainfall. In contrast, those households who did not have enough cattle for ploughing (i.e., the asset poor) de-accumulate their small livestock in the face of above-normal rainfall. The asset rich seem to de-accumulate their small livestock through the sale of livestock, though the asset poor's declining possession of small livestock in the face of above-normal rainfall seems a result of mere loss through rainfall-related disasters. The heterogeneity of asset-accumulation path across different asset status is confirmed and would be the result of heterogeneous coping strategy of the asset rich (i.e., consumption smoothing) and the asset poor (i.e., asset-smoothing) during the drought period.

The findings of this paper have several policy implications regarding household-level coping mechanisms against climatic disasters in developing countries. First, the extent of use of livestock sale as self-insurance is heterogeneous among different asset-status. Without consideration of this heterogeneity, public intervention against natural disasters may not be effective to some group in affected communities. Secondly, the effect of under- and above-rainfall on the welfare of households are also different. Although both under- and above-rainfall are aggregate shocks which may adversely affect villagers' lives, the differences in suddenness and the duration of below- and above-rainfall coupled with socioeconomic heterogeneities bring about further bifurcated reactions from asset-rich and asset-poor households.

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