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Abstract

Climate change is making El-Niños more frequent and intense. Therefore, understanding the effects of El-Niño-induced climatic events is essential to designing effective coping and adaptation strategies. We identify the impact of the 2015-16 El-Niño-induced large-scale drought on smallholder farmers' livestock holding and milk production using nationally representative data collected before and after the drought. We show that drought reduced milk production and livestock holding by 25.8% and 8.4%, respectively. Heterogenous impact analysis suggests that asset-rich households sold livestock and financed feed purchases, which insulated their milk production from the drought. In contrast, asset-poor households kept their livestock despite the severe drought and absorbed all the decline in milk production. Our findings have important implications for formulating safety net and adaptation programs targeting smallholder farmers and the livestock sector in a rapidly changing climate.

JEL-Codes: D13, O13, O44, Q18, Q54

Keywords: Drought; diff-in-diff; climate change; smallholder farmer; livestock holding

February 2024

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1. Introduction

Households in developing countries are vulnerable to considerable risk and shocks that may have long-term consequences. The most notable risk in rural settings is unpredictable rainfall (Townsend, 1994; Bellemare and Christopher, 2013), which has been exacerbating in the past few decades due to climate change (IPCC, 2014, 2021). Most households do not have the opportunity to access formal financial institutions to mitigate risk and cope with shocks. While some idiosyncratic shocks are insured through informal risk-sharing arrangements, albeit partially (Bardhan and Udry, 1999; Dercon, 2004; Dercon et al., 2005), covariate shocks, such as drought, are not insured and often have a long-term negative impact on household outcomes (Bardhan and Udry, 1999; Dercon, 2004; Dercon et al., 2005; Manccini and Yang, 2009; Carrillo, 2020).

In this paper, we identify the impact of the 2015/16 El-Niño-induced drought[1] on livestock holding and milk production of smallholder farmers using panel data from Ethiopia collected before and after the drought, which we matched with high-resolution weather data. The 2015 El-Niño was notable in its strength and devastating effects. It resulted in severe drought in Eastern Africa, Southern Africa, and Latin America, cyclones, and frost in Asia, affecting over 60 million people globally (FAO, 2016b). In large parts of Ethiopia, the drought led to the failure of two consecutive rainy seasons. As a result, it was the worst drought the country experienced in decades, leaving over 10 million people emergency food-dependent (NDRMC, 2016). The drought led to chronic undernutrition in affected areas with limited road network (Hirvonen et al., 2020). The availability of rich household panel data with a livestock module collected before and after the drought allows us to control for household unobserved heterogeneity and identify the impact of the drought on the key outcome variables of interest using the difference-in-differences (DID) estimator.

The results suggest that the drought reduced farm households' livestock holding and milk production by 8.4% and 25.8%, respectively. The key pathway through which the drought impacted livestock holding is the sale of cattle, the critical input in crop and dairy production in smallholder setups. We also find that asset-rich households account for all the livestock sales, whereas asset-poor households account for all the reduction in milk production. Asset-rich households sold livestock and financed the purchase of improved feed, which likely insulated their milk production from the drought. Asset-rich households paid about 48.3% more for the purchase of livestock feed. On the other hand, asset-poor households kept their livestock in the face of the harsh drought but absorbed a substantial decline in milk production due to water stress and feed shortage. The responses of asset-rich and asset-poor households are consistent

[1] El-Niño is the unusual warming of sea surface temperatures in the tropical Pacific occurring every 2 - 7 years and causing heavy rain, flooding, and drought (FAO, 2016b).

with the asset-smoothing theory (Fafchamps et al., 1998; Kazianga and Udry, 2006; Carter and Lybbert, 2012), which shows that at times of shocks, only households above a certain threshold level of wealth sell livestock to smooth consumption.

Finally, we find that the drought did not affect livestock holding and milk production of safety net recipient households. By responding early through emergency assistance to drought-affected areas, the government likely reduced the negative impact of the drought. Our results are robust to alternative definitions of drought. Given the importance of cattle for draft power and dairy production and the expected high prevalence of droughts because of climate change, we argue that expanding the safety net and adaptation strategies targeting the livestock sector of smallholder farming is critical. These strategies range from improving the livestock feed value chain to establishing feed stations, which some pilot studies proved to be promising (Bekele and Abera, 2008).

This paper contributes to the literature on the impact of large-scale climatic shocks on smallholder farmers. Previous studies (Rosenzweig and Wolpin, 1993; Fafchamps et al., 1998; Kazianga and Udry, 2006; Carter and Lybbert, 2012; Mogues, 2011; Hänke and Barkmann, 2017; Acosta et al., 2021) investigate the effects of shocks on the livestock holdings of smallholder farmers in different settings and farmers' responses. An important finding in this literature is that during major shocks, rich households use livestock as a buffer, but poor households endure a large decline in their consumption and hold on to their livestock. Acosta et al. (2021) particularly show that during a major drought, households get rid of large animals, such as cattle, because it becomes difficult to meet their water and fodder requirements.[2] Building on these studies, our contributions are two-fold. First, we identify the impact of the 2015-16 El-Niño-induced drought on livestock holding using a credible identification strategy (difference-in-differences) on data collected before and right after the drought. Smallholder farmers in Africa and other developing regions contributed little to the problem of climate change, but they are being affected more proportionately than industrialized countries (Wei et al., 2012; Althor et al., 2016; IPCC, 2014, 2021). Climate change will increase the frequency of extreme weather events, such as drought and flooding (IPCC, 2014, 2021). Wang et al. (2019) show that climate change is making El-Niños more frequent and intense. However, El-Niños are relatively predictable, and their effect can be significantly reduced with improved early warning and disaster preparedness systems.

Ethiopia offers an important setup to explore the impact of the 2015-16 El-Niño-induced

[2]Two other notable studies focusing on livestock holding of nomadic households are Lybbert et al. (2004) and Smith and Frankenberger (2022). Lybbert et al. (2004) study stochastic wealth dynamics of households in Southern Ethiopia and find that calving and mortality (driven by idiosyncratic shocks) are the key drivers of herd dynamics. Smith and Frankenberger (2022) evaluate the impact of a USAID-funded pastoralist program in Ethiopia and show that a "systems" approach of strengthening financial, market, agriculture, and environmental is critical to ensure the resilience of nomadic communities against shocks.

drought on the livestock sector managed by smallholder farmers. With a population of 99 million at the follow-up survey (2015-16), 70% of whom depended on rain-fed smallholder agriculture for their livelihood, Ethiopia ranks as the second most populous country in Africa and one of the most vulnerable countries to recurrent weather-related shocks. According to the emergency events database (Guha-Sapir et al., 2016), Ethiopia experienced more than 15 drought events since the 1960s, including the 2015 El-Niño-induced drought. During the past two decades, the Ethiopian government, with support from the international community, invested heavily in its disaster preparedness capacity and safety nets to better respond to central shocks. The most notable initiative is the Productive Safety Net Programme (PSNP), which was initiated in 2005 through multi-donor support. The main objective of the PSNP is to lift millions of chronically food-insecure rural households from emergency food aid to a predictable form of social protection and respond to short-term shocks, like droughts (WorldBank, 2013). The timing of the El-Niño-induced drought enables us to study how these "improved" safety net programs insulated smallholder farmers' livestock resources against the drought. With around 57 million cattle in 2014, Ethiopia also ranks as the wealthiest country in Africa and the fifth wealthiest country in the world regarding cattle holding. However, the sector is characterized by traditional management, which limits its contributions to the economy of the country (UNIDO, 2017).

Second, and more importantly, we leverage the rich livestock module of the Ethiopian Socioeconomic Survey and identify the impact of drought on milk production. To the best of our knowledge, none of the previous studies investigated the effect of shocks on milk/dairy production in developing countries. The three existing studies that examine the impact of climate variables on dairy production (Key and Sneeringer, 2014; Gisbert-Queral et al., 2021; Lin et al., 2023) use data from the United States. These studies show how even modest heat stress over the threshold significantly reduces milk production and quality in the US dairy sector. Understanding the impact of drought on milk production in low-income farming communities is essential because milk and other dairy products are key sources of high-quality protein and essential micronutrients (vitamins and minerals) that prevent stunting (Dror and Allen, 2011; Adesogan and Dahl, 2020).[3] Dairy production in smallholder setups also provides an important source of livelihood, especially for vulnerable community members, such as women and the landless (Alary et al., 2011). Our causal estimate of the impact of El-Niño-induced drought on milk production is new evidence of the additional welfare cost of climatic shocks.

The rest of the paper is structured as follows. Section 2 presents the country context. Section 3 describes the data, sample construction, and descriptive statistics. Section 4.1 discusses the

[3]The vital vitamins and minerals present in milk which prevent stunting include vitamin $A, B_1, B_2, B_3, B_5, B_6, B_{12}, D_3$, iron, iodine, zinc, folic acid, choline, calcium, phosphorus, selenium, and potassium (Dror and Allen, 2011; Adesogan and Dahl, 2020).

empirical strategy. Section 4 presents results from alternative difference-in-differences estimators. This section also discusses the mechanisms through which drought affects livestock holding and milk production and some key robustness checks. Section 5 concludes.

2. Country Context

Ethiopia is located in the Northeastern part of the Horn of Africa, bordering Kenya in the south, Djibouti and Somalia to the east, Eritrea to the north, and Sudan and South Sudan to the West. It has a total area of 1.1 million km^2 and a total population of 99 million, out of which 81 percent lived in rural areas in 2016 when the follow-up data was collected (WorldBank, 2022). Ethiopia has a tropical monsoon climate with wide topographic-induced variation classified into three climatic zones: a cool zone (Dega) 2400 m above sea level consisting of the central parts of the western and eastern section of the high plateaus, where the temperature ranges from close to freezing to 16 dc; a temperate zone (Woina Dega) between 1500 m and 2400 m above sea level, where the temperature ranges between 16 -30 dc; and the hot zone (Qola) in the lowlands below 1500 m which encompasses both tropical and arid areas, and has temperatures ranging from 27 dc to 50 dc (USAID, 2016). Annual rainfall varies from about 2000 mm in some pocket areas in southwest Ethiopia to less than 100 mm in the Afar Lowlands in the northeast, with the average being 848 mm (FAO, 2016a).

Agriculture plays a significant role in the Ethiopian economy, contributing about 35 percent of the GDP, 68.2 percent of employment, and 90 percent of export earnings (FDRE, 2016). The livestock sub-sector contributes about 45 percent to agricultural GDP (FAO, 2019), 19 percent to the overall GDP, and 16–19 percent to the foreign exchange earnings of the country (MoA, 2012). Livestock serves multiple functions in the rural household economy. In the context of rural Ethiopia, not only is livestock a source of livelihood and important input in agricultural production, but it is also a source of income to meet daily needs, protein for own consumption, manure for crop production and cooking fuel, means of transport, and store of wealth (ILRI, 2011). Around 14 million Ethiopian households (70 percent of the population) keep livestock (FAO, 2019). Consequently, the livestock sector has great potential to improve the population's livelihood and reduce poverty.

Ethiopia has the largest livestock population in Africa and the tenth largest in the world (UNIDO, 2017).[4] In 2015, the country was estimated to own about 57 million cattle, 30 million sheep, 23 million goats, and 57 million chickens, and it produced over 5.6 billion liters of milk, 1.1 million tons of beef, and 419 million eggs (FAO, 2019). With large livestock, a favorable climate, and a relatively disease-free environment, Ethiopia has great potential to develop the

[4]Considering only the cattle population, Ethiopia ranks first in Africa and fifth in the World (UNIDO, 2017).

sector (Ahmed et al., 2004). However, despite the large livestock population and favorable weather conditions, livestock output and productivity are poor due to technical, economic, and institutional constraints (FAO, 2019). Livestock production takes place through two systems: the mixed crop-livestock, which combines both crop and livestock production and is based on limited communal or private grazing areas and crop residue or stubble, and the nomadic pastoral system, which relies on extensive communal grazing (Negassa et al., 2011). Both systems are managed through inefficient and traditional methods, and as a result, the livestock sector offers low and unreliable returns, leaving many livestock-dependent households in poverty (Rettberg et al., 2017).

Ethiopia is a highly drought-prone country. As its agriculture, the livestock sector is also significantly vulnerable to climatic shocks such as drought. Since the 1960s, Ethiopia experienced more than 15 drought events (Guha-Sapir et al., 2016), considerably impacting the country's poor population. The impact of climate change is visible with the average temperature in the country increasing by $1^{o}C$, resulting in a 37.5 percent increase in the average number of hot nights between 1960-2003 (McSweeney et al., 2009). The temperature increase has led to accelerated evapotranspiration and reduced soil moisture, particularly in the central and highland areas of the country (Ministry of Environment and Forest - MoEF, 2015). Ethiopia also experienced significant variability in long-term precipitation with an overall decline in the last three decades, with some areas such as the south-central region experiencing a 20% reduction in rainfall since 1960 (Ministry of Environment and Forest - MoEF, 2015). The timing and duration of rainfall seasons will be significantly affected in the future due to the surface temperature rise in the Indian Ocean, causing more frequent droughts (USAID, 2012). Given the above, analyzing the impact of drought on the livestock sector is vital to understanding the cost of climatic shocks and designing effective coping and adaptation strategies. .

3. Data

3.1. Sampling and Data Collection

The analysis conducted in this paper uses household survey data from rural Ethiopia. To identify the impact of the El-Nino-induced drought on livestock holding and milk production, we use the two rounds of a panel data set - the Ethiopian Socioeconomic Survey (ESS) - that represents rural Ethiopian households. ESS was conducted as part of the World Bank Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA), in collaboration between the Ethiopian Central Statistics Agency (CSA) and the World Bank (WB). The key objective of the survey was to understand agriculture and its role in household wellbeing. The first round was conducted as a rural survey in 2011/12 covering only rural and small-town areas with a total sample of 333 enumeration areas (EAs) constituting 3,776 households and called the Ethiopian Rural Socioeconomic Survey (ERSS). In the subsequent two rounds conducted in 2013/14 and 2015/16, the survey was expanded to include urban areas to ensure that the data could provide nationally representative samples with a total of 433 EAs and 5,262 households, forming (ESS) the Ethiopian Socioeconomic Survey.[5]

ERSS was designed to represent Ethiopia's rural and small town population in the four major regions: Amhara, Oromia, Southern Nations, Nationalities and People (SNNP), and Tigray, using a two-stage probability sampling. In the first stage, primary sampling units of 290 rural and 43 small-town EAs were selected from EAs used by the Ethiopian Central Statistics Agency in proportion to the populations of the regions. In the second stage, 12 sample households from each rural sample EA and 10 households from each small town EA were randomly selected. We use the survey's first round to test the difference-in-differences estimator's parallel trend assumption.

The second round was conducted in 2013/14 as the ESS with an additional 1500 households living in 100 EAs in large urban towns, including the capital, Addis Ababa, using the two-stage sampling referred to above. Fifteen households were randomly selected from each urban EA. Including urban households in the second wave increased the total sample to 433 EAs and 5469 households. Since the 2015 El-Nino-induced drought happened after the second round, we use the second round as the baseline round in our difference-in-differences analysis. The third round, which we treat as the post-drought round - was conducted in 2015/2016 after the El-Niño induced drought from the same sample of EAs and households established during the second round. Attrition in the rural sample is negligible ($< 2\%$).

Data collection began in September in all rounds to avoid the effect of seasonality. The survey collects detailed socioeconomic information through five questionnaires: a household questionnaire documenting information on demographics, education, consumption, labor market activities, etc.; a community questionnaire addressed to a group of community members about EA-level resource management initiatives, community needs, actions, and achievements; two agriculture questionnaires consisting of questions about post-planting and post-harvest agricultural activities including input use, crop harvest, and utilization; and a livestock questionnaire documenting information on the number and type of livestock, change in livestock, animal health and feed, milk and egg production. ESS is the richest and nationally representative panel data set for Ethiopia - the second most populous country in Africa. Given the focus of our paper on the impact of the drought on smallholder farmers, we use the sample of households from the four

[5] See https://microdata.worldbank.org/index.php/catalog/2053 for a detailed description of ESS.

regions of Ethiopia, Tigray, Amhara, Oromia, and Southern Nations, Nationalities and Peoples region, excluding nomadic (pastoralist) households, who do not engage in crop production. However, we test the robustness of our results to the inclusion of nomadic households in Section 4.5. Descriptive statistics of key household variables of the sample households at baseline are presented in Table 2.

3.2. Weather Data

In addition to the household survey data, we constructed rainfall data from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). Most previous studies investigating the impact of drought on household welfare in Ethiopia used either self-reported measures (Dercon et al., 2005; Porter, 2012) or meteorological data (Dercon, 2004; Yamano et al., 2005; Thiede, 2014) provided by the Ethiopian meteorological agency. Self-reported data suffer from reporting bias; metrological data suffers from many missing observations and measurement errors due to large spatial coverage. There has been a decline in the number of weather stations in Africa during the past decade. According to (Lorenz and Kunstmann, 2012), the number of reporting weather stations in Africa has fallen from around 3500 to around 500 since 1990. Moreover, (Alem and Colmer, 2021) show that Ethiopia has, on average, 0.03 stations per woreda (district), which are likely placed in more surplus agricultural producer areas, probably resulting in estimates using weather stations systematically biased upward.

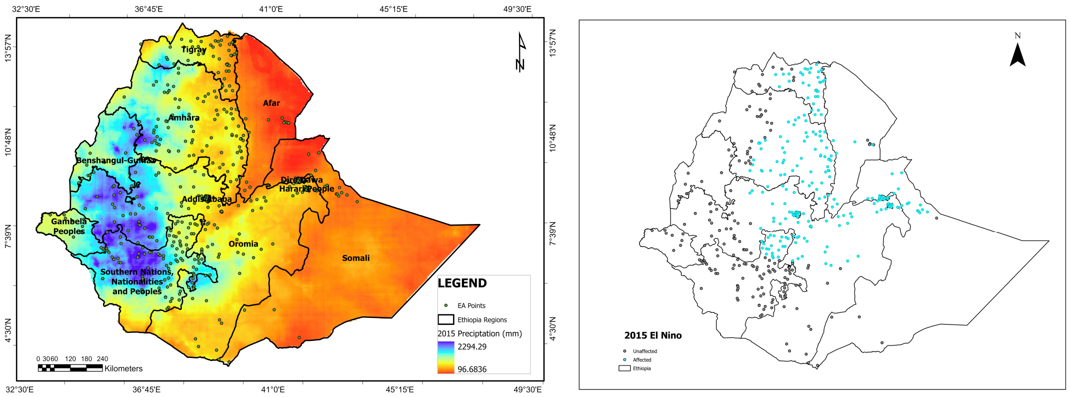
CHIRPS is a 35+ year quasi-global rainfall data set. The data contains monthly, pentadal, and daily rainfall data from 1981 to the present day with 0.05-degree (5×5 km) spatial resolution satellite imagery. CHIRPS creates gridded time-series rainfall data with fine resolution through in-house climatology and in-situ station data usable for trend analysis and seasonal drought monitoring (Funk et al., 2015). For this study, we used CHIRPS data for a spatial resolution of around 5 km (at the equator) and a temporal resolution of one month. The CHIRPS data has been used extensively in previous research, which investigates the effects of weather shocks (Hirvonen et al., 2020; Tambet and Stopnitzky, 2019; Aragón et al., 2018).

3.3. Sample Construction

We use the household latitude and longitude coordinates from the Ethiopian Socioeconomic Survey (ESS) to match the CHIRPS data using an inverse-distance weighted average of the four nearest satellite observations. After matching the two data sets, we followed Shah and Steinberg (2017) and Mahajan (2017) and defined drought, our primary explanatory variable of interest, as a binary variable if rainfall in 2015 was below the 20^{th} percentile within the enumeration area over the long-term period (i.e., 1981–2015). In the "Results" section, we check for the robustness of the results to several alternative definitions of drought.

In figure 2, we present the map of Ethiopia. Panel (a) shows the different regions, the ESS villages (EAs) distribution, and rainfall distribution during the El Nino year. Panel (b) shows the location of drought-affected and unaffected EAs based on our definition of drought using the CHIRPS data.

The scale of the El-Nino-induced drought is evident in Figure 2, which shows the descriptive statistics of drought in the whole sample and by region. Panel (a) shows that the drought affected about 52 percent of the sample households. A larger proportion of households were affected in the Amhara region than in the rest (panel b). This was followed by households in Tigray and Oromia regions.



(a) Regions, ESS EAs, and Rainfall Dist. - 2016 **(b)** Regions and ESS EAs by Drought Status

Figure 1: Maps of Ethiopia

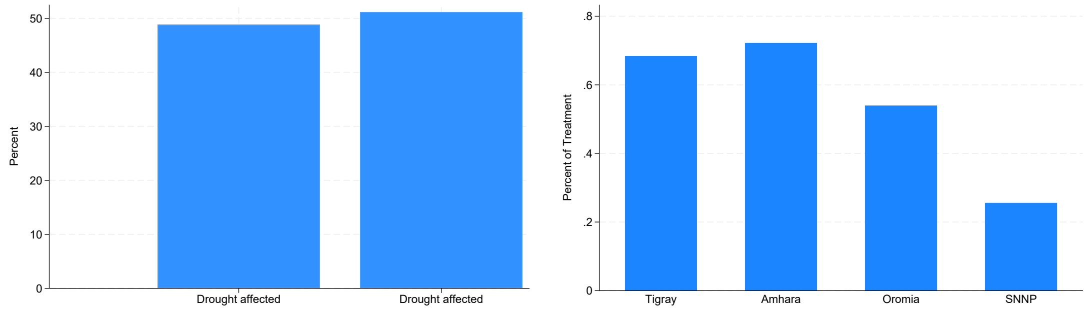
Notes: This figure displays the map of Ethiopia. Panel (a) shows the regions of Ethiopia, the sample EAs and the rainfall distribution for the El-Nino year obtained from the CHIRPS data. Panel (b) shows the regions and sample EAs by drought status.

Our outcome variables of interest are livestock holding measured in the Tropical Livestock Unit (TLU) and the average daily milk produced per cow. We converted livestock holding of households using the conversion factors provided by FAO (2011). The final sample comprised 2661 households for the livestock holding sample and 2641 for the milk production sample. The difference is that we dropped 20 households with unrealistically high values for milk production.

4. Results

4.1. Identification Strategy and Validation

To assess the impact of the drought triggered by the 2015 El Niño on livestock holding and milk production, we employ the difference-in-differences (DID) estimator. The integration of extensive



(a) Whole Sample **(b)** By Region

Figure 2: Incidence of Drought

Notes: This figure presents the incidence of drought in the El-Nino year. Drought status = 1 if rainfall in 2015 was below the 20th percentile within the enumeration area over the long-term period (i.e., 1981–2015). Panel (a) shows drought status for the whole sample. Panel (b) shows drought status by region.

household data within the ESS panel, along with high-resolution weather data, allows us to analyze the impact of the drought while accounting for both observable and unobservable, time-invariant household characteristics. The method compares the outcome variables of households affected by the drought with those unaffected, both before (2013/14) and after (2015/16) the drought. The DID estimator is derived from the following regression equation:

$$Y_{it} = \alpha + \beta D_i + \gamma Year_i + \delta D_i \times Year_t + \eta \boldsymbol{X}_{it} + \epsilon_{it} \quad (1)$$

where Y_i is the outcome variable of interest (livestock holding in TLU and milk/cow/day) for household i at period t, and D is an indicator variable equal to 1 if the household was affected by the drought, and 0 otherwise. Our measure of drought is constructed from the rainfall data discussed in the preceding section. $\boldsymbol{X}_{it}$ is a vector of relevant covariates, and ϵ_{it} is an idiosyncratic error term. δ, the parameter estimate of the interaction between D_i and $Year_i$ gives the causal effect of the drought.

The DID estimator relies on the strong assumption that, in the absence of the treatment, average outcomes for the treated and comparison households would have followed parallel trends over time, i.e., the *trend* in the outcome variables of interest must be similar for both treatment and control groups pre-treatment (Angrist and Pischke, 2009). The availability of two rounds of panel data before the drought (2011/12 and 2013/14) allows us to test if the parallel trend assumption holds. If that is the case, the two groups can be compared, and the DID estimator identifies the impact of the drought.

Table 1 presents ATT estimates from the DID estimator on the impact of the 2015/16 drought

Table 1: Validating Parallel Trend Assumption

	(1)	(2)	(3)	(4)
	Livestock Holding		Milk Production	
Difference in average outcomes (ATT)	-0.00321	0.00788	0.0447	0.0334
	(0.0932)	(0.0973)	(0.0727)	(0.0730)
Baseline Controls?	No	Yes	No	Yes
Observations	1978	1978	1974	1974

Notes: This table reports ATT estimates of the impact of the 2015/16 drought on livestock holding and milk production in 2011/12 to test for the parallel trend assumption. Columns 1 and 2 report ATT estimates on the impact of drought on TLU from the DID estimator without and with controls, respectively. Columns 3 and 4 report ATT estimates on the impact of drought on milk production/cow/day from DID estimator without and with controls, respectively. Standard errors reported in parentheses are clustered at the enumeration area level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

on livestock holding and milk production in 2011/12, when no household experienced drought. The results suggest that the El-Niño-induced drought did not affect both outcome variables of interest - livestock holding and milk production in 2011/12. This suggests that the parallel trend assumption holds and that the difference-in-differences estimation is a valid method to identify the impact of the drought.

4.2. Impact on Livestock Holding and Milk Production

We present descriptive statistics of key variables at baseline in Table 2. About 76% of the households are male-headed, the maximum level of education in the average household is approximately 4.5 years of schooling, and households, on average, have five members. Rural Ethiopia exhibits one of the lowest land holdings in Sub-Saharan Africa (Deininger et al., 2017) with the average holding per household being 1.6 ha land and 0.33 ha on a per capita basis. Table 2 also shows that about one-third of households have access to credit, and 27% own a non-farm enterprise. Livestock is the most critical asset in the context of rural Ethiopia, with an average holding of 2.48 livestock in Tropical Livestock Units.[6] At baseline, households, on average, produced 0.64 liters of milk/cattle.

Table 3 shows the results on the impact of the 2015/16 El-Niño-induced drought on livestock holding and milk production from the difference-in-differences estimator. All regressions consistently suggest that the drought reduced livestock holding significantly. The most conservative estimates from column 2 DID (controlling for baseline covariates) indicate that the drought reduced livestock holding of the treatment group by 0.20 units. Given the mean livestock holding

[6] FAO (2011) proposes the following units to convert household livestock holding to standard Tropical Livestock Units: Cattle=0.5, Goat and Sheep=0.1, Horse = 0.5, Mule=0.6, Donkey = 0.3, Camel=0.7 and Chicken=0.01.

Table 2: Descriptive statistics at baseline

Male head	0.753 (0.432)
Head's age	46.49 (15.29)
Maximum education in the household	4.885 (3.816)
Household size	5.047 (2.287)
Land holding	1.575 (4.537)
Access to credit	0.307 (0.462)
Owns a non-farm enterprise	0.311 (0.463)
Owns a mobile phone	0.383 (0.486)
Tigray	0.124 (0.329)
Amhara	0.277 (0.448)
Oromia	0.260 (0.439)
SNNP	0.339 (0.474)
Livestock in TLU	2.332 (2.766)
Average daily milk/cattle(litters)	0.609 (1.027)
Observations	2661
Clusters (Enumeration Areas)	251

Notes: This table presents summary statistics of variables at baseline (pre-drought) for the pooled sample (treatment and control group combined).

of the control group at baseline is 2.39 in tropical livestock units, the effect of the drought is equivalent to about 8.4% reduction in livestock.

Columns 3-4 of Table 3 report results on the impact of the drought on milk production from the DID estimator. Similarly, all the regression results suggest that the drought significantly reduced milk production in the drought-affected areas. DID results controlling for baseline covariates reported in column 4 indicate that milk production was reduced by 0.16 litters (25.8%)

Table 3: The Impact of Drought on Livestock Holding and Milk Production

	(1)	(2)	(3)	(4)
	Livestock Holding		Milk Production	
Difference in average outcomes (ATT)	-0.208**	-0.195**	-0.177**	-0.160**
	(0.0868)	(0.0886)	(0.0691)	(0.0737)
Control mean	2.392		0.620	
	(3.123)		(0.854)	
Baseline controls?	No	Yes	No	Yes
Observations	2661	2661	2641	2641

Notes: This table reports ATT estimates of the impact of the 2015/16 drought on livestock holding and milk production. Columns 1 and 2 report ATT estimates on the impact of drought on TLU from the DID estimator without and with controls, respectively. Columns 3 and 4 report ATT estimates on the impact of drought on milk production/cow/day from the DID estimator without and with controls, respectively. Standard errors reported in parentheses are clustered at the enumeration area level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

per day/cow in the drought-affected group compared to the non-drought-affected group.

Households keep different types of livestock for different purposes. Cattle (more importantly oxen) are the critical capital inputs used for farming in smallholder setup (Gilligan and Hoddinott, 2007), and investment as a buffer stock for consumption smoothing, especially in semi-arid tropical areas (Rosenzweig and Wolpin, 1993; Fafchamps et al., 1998; Kazianga and Udry, 2006; Carter and Lybbert, 2012; Acosta et al., 2021). Cows are kept to produce milk and milk products for household consumption and the market (FAO, 2019; Alary et al., 2011; Acosta et al., 2021), and smaller livestock, such as sheep, goats, and chicken, are kept for own consumption and sales to meet emergency cash needs (Pica-Ciamarra et al., 2015; Acosta et al., 2021). From a social protection and public policy point of view, it is therefore essential to understand the impact of the drought on livestock holding by livestock type.

In Table 4, we divide livestock ownership into cattle, small animals, and other animals and present the impact of the drought by livestock type. The results suggest that the impact of drought on livestock holding is driven primarily by its effect on cattle and small animal holding. Comparing the ATT effects on cattle holding reported in column 1 of Table 4 (-0.139) with the ATT impacts reported in column (2) in Table 3 (-0.195), we note that about 71.3% of the impact of the drought on livestock is through its effect on cattle holding. We discuss the implications of these results in section 4.5, where we tease out the mechanisms.

4.3. Heterogenous Impacts

We check for heterogenous effects of the 2015/16 drought based on three critical socioeconomic variables - the gender of the head, household wealth status, and access to safety nets. There is

Table 4: The Impact of Drought by Livestock Type

	(1) Cattle	(2) Small Animals	(3) Other Animals
Difference in average outcomes (ATT)	-0.139**	-0.0742**	0.0176
	(0.0656)	(0.0295)	(0.0209)
Baseline controls?	Yes	Yes	Yes
Observations	2661	2661	2661

Notes: This table reports ATT estimates of the impact of the 2015/16 drought on livestock holding by livestock type from the DID estimator. Column 1 reports estimates on the impact of drought on cattle holding in TLU. Column 2 reports estimates on the impact of drought on small animal holding in TLU. Column 3 reports estimates on the impact of drought on other animals in TLU. Standard errors reported in parentheses are clustered at the enumeration area level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

existing solid evidence indicating that female-headed households are more vulnerable to shocks, less likely to have access to modern technologies, and often face constraints in navigating through input and product markets (Bardhan and Udry, 1999; Dercon, 2002; Alem et al., 2010). In Figure 3, we report the effects of the drought by the gender of the head of the household on livestock holding and milk production. Contrary to the expectation, we note that livestock holding of both male-headed and female-headed households have been affected negatively, but the effects are statistically significant for male-headed households only. The reason is likely because 76% of the households are male-headed (Table 2) and that they already had a larger number of livestock holding (2.73 units) than female-headed households (1.66 units) at baseline, with a statistically significant difference in mean values (p-value = 0.000). Male-headed households had more livestock and lost more because of the drought. We also note in Figure 3 that the effect of the drought on milk production is statistically significant for male-headed households only.

To check for heterogenous effects of the drought-based wealth, we classified households as asset-rich and asset-poor based on ownership of two cattle and above at baseline. Cattle ownership in rural Africa is important not only as a source of draft power but also as a store of wealth (Hoddinott, 2006; Hänke and Barkmann, 2017). Owning two cattle, the key capital input for farming is the threshold used by previous studies to define rural small-holder farm households. Scott (2019) uses several iterative estimations using the same data set from rural Ethiopia and shows that two cattle can be used as the benchmark to classify rural households as asset-rich and poor. Based on this criteria, about 57% of the sample are asset-rich at baseline.

We plot the parameter estimates from the DID regressions on the heterogeneous impact of the drought on livestock holding and milk production by livestock asset in Figure 4. The results suggest that the drought affected asset-rich and asset-poor households' livestock holdings. Still, the effect is statistically significant for asset-rich households only for livestock holding and asset-

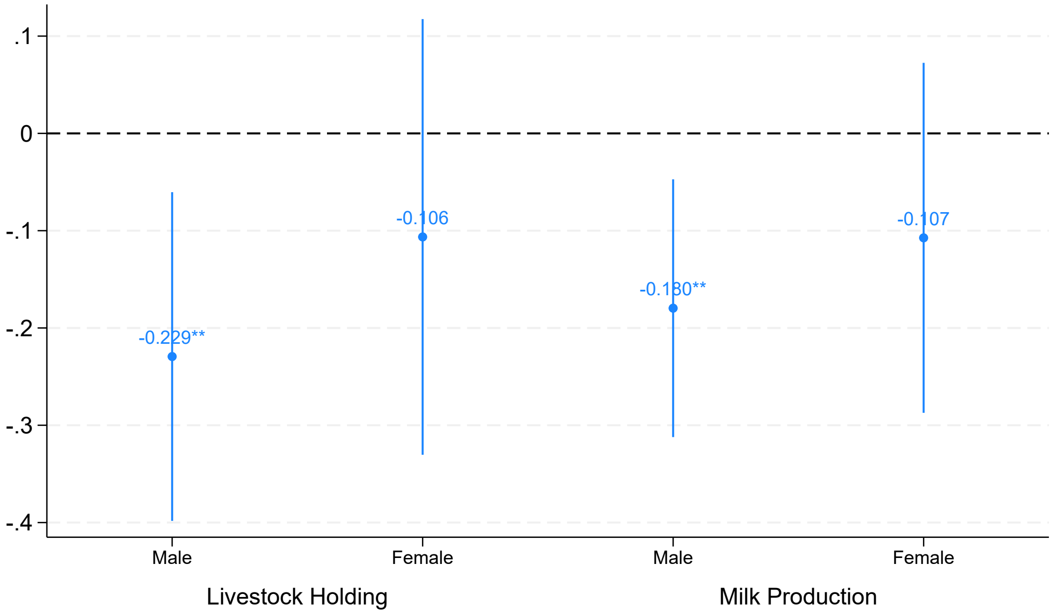


Figure 3: Heterogenous Impact by Gender of Head

poor households only for milk production. We note that the drought reduced livestock holding of asset-rich households by about 0.28 tropical livestock units or by 11.7%. This finding is unsurprising given that we used livestock to measure wealth, and livestock-rich households lost more livestock than livestock-poor households. However, we note from Figure 4 that the drought reduced milk production of livestock-poor households more proportionately than livestock-rich households. These households lost milk production by 0.18 liters/cow/day or by 29%. This corresponds to a 13% increase in the ATT effects of the drought compared to what we reported in the main regressions in Table 3. In the next section, we use livestock feed data to examine the possible mechanisms that explain these heterogeneous effects.

Finally, we investigate the impact of the drought by access to safety nets. Ethiopia is a drought-prone country that has experienced more than 15 drought events since the 1960s, resulting in significant loss of life and household wealth (Guha-Sapir et al., 2016). The Ethiopian government has recently improved its disaster preparedness capacity to respond to major natural shocks. The most notable initiative is the multi-donor-supported Productive Safety Net Programme (PSNP), initiated in 2005 to lift millions of chronically food-insecure rural households from emergency food aid to a predictable form of social protection (WorldBank, 2013).

Figure 5 presents the parameter estimates on the heterogeneous impact of the drought on

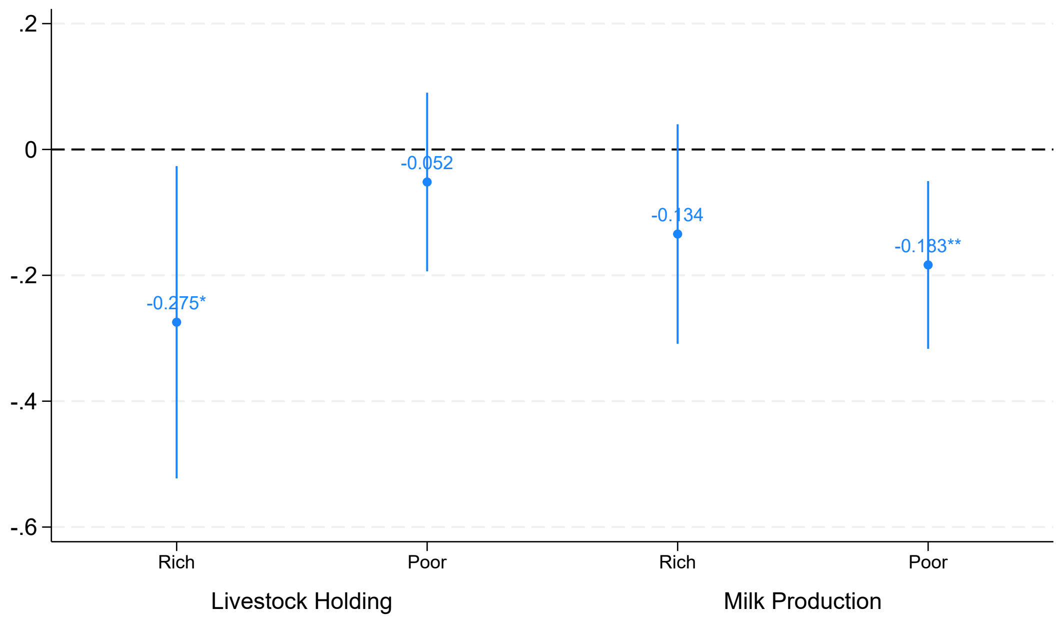


Figure 4: Heterogenous Impact by Wealth

livestock holding and milk production by access to safety nets. The results suggest that the drought did not statistically affect livestock holding of safety net recipient households. Still, its effect on non-recipient households is marginally significant. Similarly, for milk production, the impact of the drought is significant only for non-recipient households. We note that both effects on non-recipient households are significant at the 10 percent only. Taken together, the results suggest that early intervention by the Ethiopian government might have reduced the impact of the 2015/16 El-Niño-induced drought.

4.4. Mechanisms

From an adaptation and social protection point of view, it is important to tease out the mechanisms through which the El Niño-induced drought reduced smallholder farmers' livestock holding and milk production. We begin by differentiating the source of livestock loss by death, sales, and own consumption and report the ATT effects from the DID estimator in Table 5. The results suggest that the drought affected only livestock sales, with no statistically significant impact on livestock death and consumption. Specifically, column (2) indicates that drought-affected

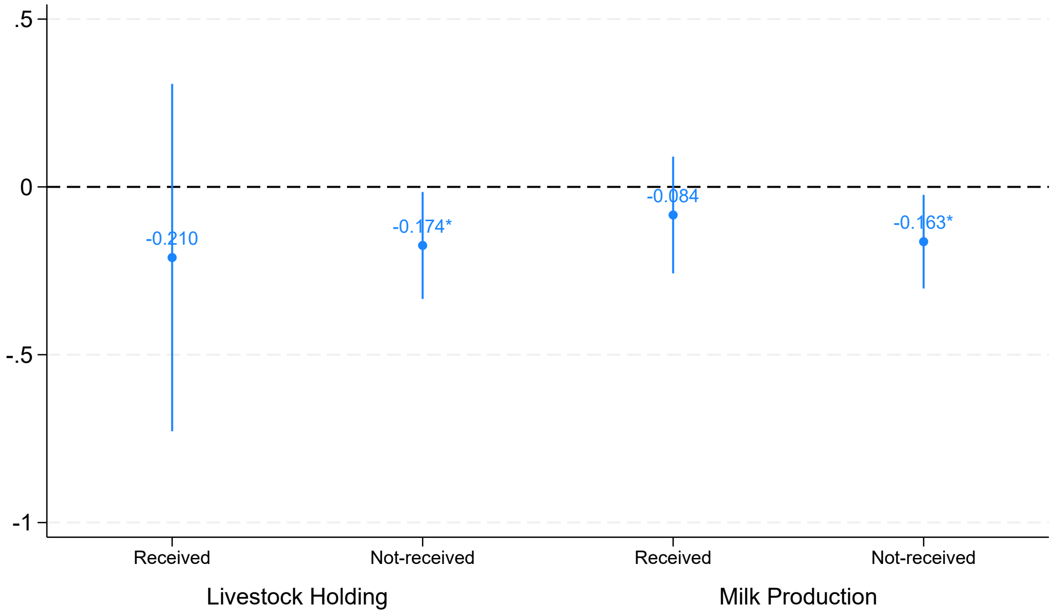


Figure 5: Heterogenous Impact by Safety Net

households sold 0.09 units of livestock on average.[7]

Table 5: Mechanisms - Livestock Death, Sales, and Consumption

	(1) Livestock Death	(2) Livestock Sales	(3) Livestock Consumption
Difference in average outcomes (ATT)	0.0377	0.0930**	0.0115
	(0.0470)	(0.0449)	(0.0128)
Baseline controls?	Yes	Yes	Yes
Observations	2661	2657	2656

Notes: This table reports ATT estimates of the impact of the 2015/16 drought on livestock death, livestock sales, and livestock consumption from the DID estimator. Standard errors reported in parentheses are clustered at the enumeration area level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Next, we investigate the source of livestock loss (livestock death, sales, and consumption) for livestock-rich and livestock-poor households using similar regressions and report the results in Table 6. We note that the impact of the drought on livestock sales is statistically significant for

[7]The sex composition of cattle held or sold may be necessary for the present value of household assets held. It is particularly important for milk production. We used the 2015/16 wave of the ESS survey to check for the heterogeneous impact of the drought on oxen and cow death, sales, and consumption. We did not find statistically significant differences with the ones we report in Table 5.

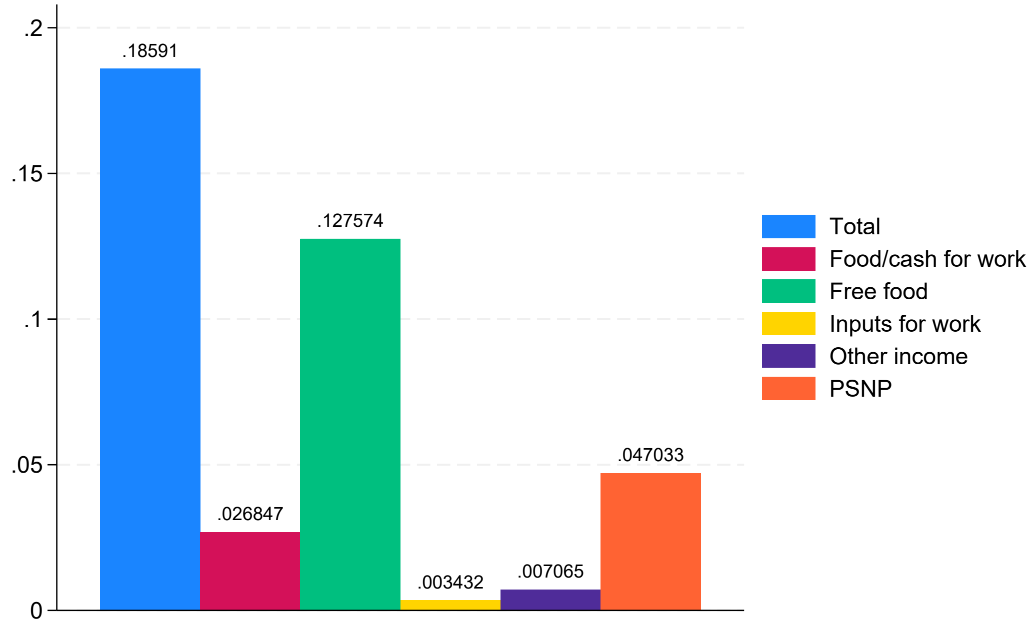


Figure 6: Descriptive Statistics on Safety Net

livestock-rich households only. The ATT effects of livestock sales for livestock-rich households reported in Table 6 are very similar to the ATT effects for livestock sales of the whole sample reported in Table 5, which suggests that livestock sales by asset-rich households account for all livestock sales post-drought.

To shed light on why livestock-rich households sold livestock in our sample, we use information on livestock feed purchase collected in the post-drought wave (2015/16) of the Ethiopian Socioeconomic Survey.[8] We estimated three regressions: whether a household used improved feed or not, whether the household purchased improved feed or not, and the log of expenditure on feed. The results reported in Table 7 suggest that the drought did not affect all three outcome variables when considering the entire sample. However, by dividing the sample into livestock-rich and livestock-poor, we find that the drought has a marginally significant effect (at 10%) on the probability of feed purchase and the log of purchased feed cost by livestock-rich households. These households, on average, paid 48.3% more for feed purchases than livestock-poor households. This provides suggestive evidence that livestock-rich households sold livestock at least in part to generate cash to finance the cost of purchased feed, and this may have insulated their

[8] We use data on feed purchase and use from the post-drought survey (2015/16) only due to inconsistency in the feed data collection between the 2013/14 and 2015/16 waves.

Table 6: Mechanisms - Livestock Death, Sales, and Consumption by Asset Holding

	(1) Livestock Death	(2) Livestock Sales	(3) Livestock Slaughter
Asset Rich			
Difference in average outcomes (ATT)	0.111	0.0913*	0.00913
	(0.0827)	(0.0550)	(0.0191)
Observations	1392	1389	1389
Asset Poor			
Difference in average outcomes (ATT)	-0.0423	0.0987	0.0149
	(0.0358)	(0.0750)	(0.0121)
Observations	1269	1268	1267

Notes: This table reports ATT estimates of the impact of the 2015/16 drought on livestock death, livestock sales, and livestock consumption from the DID estimator by asset holding. Standard errors reported in parentheses are clustered at the enumeration area level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

milk production from the drought.

Table 7: The Impact of Drought on Feed Purchase and Use

VARIABLES	(1) Whole Sample	(2) Asset Rich	(3) Asset Poor
Impact on the Probability of Improved Feed use	0.019	0.030	0.002
	(0.017)	(0.025)	(0.012)
Impact on the Probability of Feed Purchase	0.035	0.068*	-0.008
	(0.027)	(0.038)	(0.021)
Impact on the Total log of Purchased Feed Cost	0.269	0.483*	-0.011
	(0.172)	(0.247)	(0.123)
Observations	2,661	1,392	1,269

Notes: This table reports OLS estimates of the impact of the 2015/16 drought on livestock feed use using the post-drought (2015/16) data. Standard errors reported in parentheses are clustered at the enumeration area level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Our finding that livestock-rich households sold more livestock during drought is consistent with previous studies (Rosenzweig and Wolpin, 1993; Fafchamps et al., 1998; Kazianga and Udry, 2006; Carter and Lybbert, 2012; Acosta et al., 2021). Rosenzweig and Wolpin (1993) uses data from rural India and shows that farmers invest in bullocks for productive use and sell them to smooth consumption when weather outcomes are poor. Fafchamps et al. (1998) offer limited evidence that households in the West African semi-arid tropics use livestock sales and purchases as consumption smoothing strategies during rainfall shocks. Kazianga and Udry (2006) study patterns of consumption smoothing in rural Burkina Faso and find that households smooth consumption using stored grain but not livestock. They find that particularly poor households endure a significant decline in consumption due to shocks to hold onto their livestock. Carter and Lybbert (2012) formalize this finding by constructing a poverty trap model that shows only households above a certain threshold level of wealth sell livestock to smooth consumption during shocks. Using household panel data from Burkina Faso, these authors show that households above the threshold level of wealth almost fully protect their consumption from weather shocks by selling livestock. In contrast, households below the threshold level of wealth guard their livestock even when they face a significant decline in income.

More recently, Acosta et al. (2021) use large global data collected from 150,000 households matched with multi-scalar climatic drought index and show that livestock portfolio plays a significant role in buffering against shocks, but its effect is context-dependent. These authors find that the length and intensity of shocks, like drought, determine the buffering capacity. During shocks, households first cope with stored grain and savings to smooth consumption and keep livestock (Udry, 1995; Kazianga and Udry, 2006). To cope with more severe shocks, households first sell small animals, like poultry, goats, sheep, and pigs, and sell large animals, such as cattle, when the shocks become extreme (Fafchamps et al., 1998; Acosta et al., 2021). During severe droughts, where there is water stress and a shortage of fodder, large animals, like cattle, become liabilities (Acosta et al., 2021).

Consistent with these studies, we find that livestock-rich households sold livestock to finance the feed cost to insulate their milk production and possibly to smooth consumption. However, livestock-poor households kept their livestock despite the severe drought and its effect on consumption. Moreover, consistent with Acosta et al. (2021), smallholder farmers in rural Ethiopia sold large animals, more importantly, cattle. This is understandable because the 2015/16 El-Niño-induced drought was one of the most severe droughts Ethiopia faced in decades (FAO, 2016b; NDRMC, 2016) Given the importance of cattle for draft power in rural Ethiopia, the reported significant impact has important implications for the long-term wellbeing of smallholder farmers because selling off important livestock like cattle (oxen and cows) will affect the households' draft power capacity for the next production seasons, and wealth dynamics from cattle reproduction.

Finally, livestock sales, feed shortage, and water stress likely explain the 26% reduction in milk production by drought-affected households. There is notable scientific evidence linking the decline in milk production to drought. Andrade et al. (2017) use long time series data from Brazil, showing strong links between drought indices obtained through remote sensory devices and milk production. (Abbas et al., 2019) show that Pakistan's drought threatens every aspect of dairy production, including milk. More recently, USFAS (2022) shows that the EU-wide drought in 2022 significantly reduced EU27 dairy herd and milk production.

4.5. Robustness Checks

We check for the robustness of our results using two robustness checks. First, we reconstruct the drought variable using three alternative measures: i) self-reported drought based on subjective responses by households to the question of whether they experienced drought or not, ii) if the village experienced 1 SD less rainfall from the 30-year long-term mean, and iii) if the village experienced 15 percentile less rainfall from the long-term mean.[9]

The results remain fairly robust to changes in the definition of drought. DID estimates reported in Tables A.1 - A.3 in the appendix are similar to the main results we reported in Table 3 in magnitude and statistical significance. The impact of the drought on livestock holding remained virtually the same when we used self-reported drought. However, when we use the less than 1 SD and 15 percentile less rainfall measures, the magnitudes of the drought coefficient decline by about 4 to 5 percentage points. So does the statistical significance. This is expected because these measures assume severe drought.

Second, we re-estimate the main ATT effects, including the sample of households from the nomadic regions, and present the results in Table A.4 in the appendix. The ATT effects on livestock holding (column 1) are higher than the results generated using the sample of smallholder farmers and reported in Table 3. These results are expected because the livelihood of the nomadic households depends almost exclusively on livestock keeping. The more livestock the household has, the more likely it will be affected.

5. Conclusion

The 2015/2016 El-Niño-induced drought negatively affected the livelihood of over 60 million people globally FAO (2016b). We use the exogenous variation in the prevalence of the drought to investigate its effects on livestock holding and milk production in rural Ethiopia, one of the most severely affected countries. The availability of nationally representative household panel data - the Ethiopian Socioeconomic Survey - collected before and after the drought gave us the ideal setup to implement difference-in-differences estimation using alternative matching methods.

We find that the drought reduced livestock holding of smallholder farmers by about 8.4% and milk production by about 25.8%. We also show that the main livestock affected by the drought are cattle, the key assets that serve as a source of draft power and dairy products in smallholder agriculture. Consistent with the predictions of the asset poverty trap model (Kazianga and Udry, 2006; Carter and Lybbert, 2012), we find that livestock sales by livestock-rich households drive the impact of the drought on livestock holding. Livestock-rich households sold livestock and

[9] 26% of the respondents of the rural sample of ESS reported that they experienced drought.

financed the purchase of improved feed, which likely insulated their milk production from the drought. However, livestock-poor households kept their livestock despite the large-scale drought. The results remain robust to changes in the measures of drought.

Our findings are important for formulating safety nets, programs, and adaptation strategies targeting the livestock sector and smallholder farmers. Disaster and relief agencies and NGOs often respond to drought by providing emergency food assistance (such as free food distribution and food-for-work programs) to save lives. Research suggests these interventions have been effective (Gilligan and Hoddinott, 2007; Alem and Broussard, 2017). However, given the predicted frequency of drought in the future, specific adaptation plans that address households' livestock holdings are urgently needed. To this end, improving the livestock feed value chain and establishing livestock feeding stations, which some research has proved to be effective, is crucial (Bekele and Abera, 2008). These adaptation strategies will protect household consumption and assets from shocks and help improve the productivity and economic contribution of the livestock sector in Sub-Saharan Africa, which appears to be very low currently.

Weather insurance is the second possible policy instrument that can reduce the impact of weather shocks on smallholder households' livestock holding. Previous experimental research conducted by (Janzen and Carter, 2019) shows that weather insurance reduced the likelihood of costly shocks coping strategies such as selling assets by more affluent households and cutting own consumption by poorer households in rural Kenya. Given the relative predictability of El-Niños, weather insurance, combined with early warning systems, could reduce the impact of large-scale droughts on livestock holding and the welfare of smallholder farmers.

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Drought, Livestock Holding and Milk Production: A Difference-in-Differences Analysis (Online Appendix)

January 31, 2024

Contents

1. Robustness Checks

Table A.1. Robustness Check - Self Reported Drought

	(1) Livestock Holding	(2) Milk Production
Difference in average outcomes (ATT)	-0.215**	-0.127**
	(0.0930)	(0.0624)
Baseline controls?	Yes	Yes
Observations	2661	2641

Notes: This table reports ATT estimates of the impact of the 2015/16 drought on livestock holding and milk production using self-reported drought. Columns 1 reports ATT estimates on the impact of drought on TLU from the DID estimator. Columns 2 reports ATT estimates on the impact of drought on milk production/cow/day from the DID estimator. Standard errors reported in parentheses are clustered at the enumeration area level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Table A.2. Robustness Check - Based on Standardized Deviation (<-1 SD)

	(1) Livestock Holding	(2) Milk Production
Difference in average outcomes (ATT)	-0.144*	-0.130*
	(0.0859)	(0.0729)
Baseline controls?	Yes	Yes
Observations	2661	2641

Notes: This table reports ATT estimates of the impact of the 2015/16 drought on livestock holding and milk production. Drought = 1 if the EA experienced 1 SD less rainfall than the long-term mean. Columns 1 reports ATT estimates on the impact of drought on TLU from the DID estimator. Columns 2 reports ATT estimates on the impact of drought on milk production/cow/day from the DID estimator. Standard errors reported in parentheses are clustered at the enumeration area level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Table A.3. Robustness Check - Based on Less Than 15 Percentile

	(1) Livestock Holding	(2) Milk Production
Difference in average outcomes (ATT)	-0.158*	-0.145*
	(0.0859)	(0.0735)
Baseline controls?	Yes	Yes
Observations	2661	2641

Notes: This table reports ATT estimates of the impact of the 2015/16 drought on livestock holding and milk production. Drought = 1 if the EA experienced 15 percentile less the long-term mean. Columns 1 reports ATT estimates on the impact of drought on TLU from the DID estimator. Columns 2 reports ATT estimates on the impact of drought on milk production/cow/day from the DID estimator. Standard errors reported in parentheses are clustered at the enumeration area level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Table A.4. Robustness Checks - Including Nomadic Households

	(1) Livestock Holding	(2) Milk Production
Difference in average outcomes (ATT)	-0.288**	-0.122*
	(0.124)	(0.0644)
Baseline controls?	Yes	Yes
Observations	3401	3379

Notes: This table reports ATT estimates of the impact of the 2015/16 drought on livestock holding and milk production, including the sample of nomadic households. Columns 1 reports ATT estimates on the impact of drought on TLU from the DID estimator. Columns 2 reports ATT estimates on the impact of drought on milk production/cow/day from the DID estimator.