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IFPRI Discussion Paper 02242

February 2024

Small-Scale Irrigation Protects Farmers from Climate-Extreme Events
Insights from the 2015/2016 ENSO in Ethiopia

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ABSTRACT

The El Nino Southern Oscillation (ENSO) weather event of 2015/16 caused severe drought conditions in northern and central Ethiopia affecting the welfare of millions of farmers in late 2015 and early 2016. Using nationally representative panel data collected in 2012 and 2016 and recent advances in the difference-in-differences literature, this paper explores the effects of the 2015/16 drought and the potential role of irrigation in reducing the adverse effects of the drought. We find that the drought caused, on average, a 37 percent reduction in net annual crop income, an 8 percent decline in area cultivated, a 3 percent decline in household dietary diversity score, and a 10 percent decline in the share of harvest sold for rainfed farmers. On the other hand, irrigating farmers affected by the drought managed to increase their daily expenditures by 72 percent of their average daily food expenditure in the pre-drought period, and maintained their net crop income, size of cultivated land, household dietary diversity, and share of harvest sold to the market. Overall, while rainfed agricultural producers suffered sharp declines in welfare, those farmers with access to irrigation maintained their economic status. The results suggest that irrigation protected farmers from the adverse effects of the 2015/16 ENSO event and given increasing climate variability in Ethiopia, the government should intensify its investment and support to irrigation development in the country.

Keywords: ENSO, Drought, Irrigation, Resilience, Ethiopia

JELclass: Q12, Q15, Q25, Q54

ACKNOWLEDGMENTS

This work was funded by the Feed the Future Innovation Laboratory for Small-Scale Irrigation (ILSSI) which was supported by the United States Agency for International Development. It was carried out under the CGIAR Research Program on Water, Land, and Ecosystems (WLE) and the CGIAR Initiative on NEXUS Gains. The authors thank Gashaw Abate, Seid Yimam, Tiruwork Arega, and Michael Mann for their help and support. Any opinions and conclusions expressed herein are solely those of the authors and do not reflect the views of the International Food Policy Research Institute or the World Bank.

1 Introduction

The intensity and frequency of drought has been increasing in Ethiopia with welfare-harming impacts for millions of people. For example, the 2015 drought, which was associated with an El Niño-Southern Oscillation (ENSO) event affected 9.7 million people in the central and northern parts of the country. The drought impacted pre-existing fragile Ethiopian communities that were already relatively lower ranked in key welfare indicators compared to other regions, further exacerbating existing socio-economic inequities. Overall, the effects of the drought on the national economy were modest, with a dip in national GDP by 1.6 percent and agricultural GDP by 3.6 percent according to Koo et al. (2019), partly because the relative spatial concentration of the drought was skewed to traditionally lower productivity areas (Warner and Mann, 2018).

The spatial distribution of the drought masked its severity for the approximately 10 million people who were subjected to its adverse impacts and did not have the ability to withstand a drought that was reported to be the worst in five decades (Sohnesen, 2020). The effect of the 2015 drought has not been widely studied, except for Hirvonen, Sohnesen, and Bundervoet (2020) who analyzed its effect on nutritional status of children, Sohnesen (2020) on consumption, and Koo et al. (2019) on national and agricultural GDP. The current study contributes to our understanding of the effect of the 2015 drought on net crop income, cultivated area, average daily food expenditure, household dietary diversity, and market participation. The study also explores whether access to irrigation has helped farmers withstand the adverse effects of drought.

Using nationally representative panel data collected in 2012 and 2016 from households that were and were not affected by the drought, we estimate a difference-in-differences (DID) regression to explore the effects of the drought and its heterogeneous effects by irrigation status. The study used recent developments in the DID literature to estimate doubly robust DID that allows the parallel trend assumption to be conditioned on selected baseline characteristics that can determine the evolution of the outcome variables with bootstrap procedures that allow for asymptotically valid inference (Sant'Anna and Zhao, 2020; Callaway and Sant'Anna, 2021).

As expected, the results show that the 2015 drought particularly affected rainfed farmers. The net crop income of rainfed farmers declined by 37 percent (4,250 Ethiopian Birr in real 2012 prices or US\$239[1]), the size of land they cultivate decreased by 0.12 hectares, their household dietary diversity score dropped by 0.17, and the share of crop harvest sold to the market dropped by 10 percent. On the other hand, irrigating farmers, that were in drought affected areas, managed to increase their daily expenditure on food by 72 percent (an increase of 23 Ethiopian Birr in real 2012 prices or US\$ 1.3), maintain their net crop income, size of cultivated land, household dietary diversity, and share of harvest sold to market. In other words, while rainfed agricultural producers suffered sharp declines in welfare, those farmers with access to irrigation maintained, their economic status. The results provide quantitative evidence concerning the role of irrigation as an important climate smart agricultural intervention to improve the resilience of farming households in the face of major shocks such as the 2015 ENSO drought.

2 Drought, Irrigation, and Resilience

Drought is an insidious natural hazard that is caused by significant reduced amounts of precipitation than what is generally considered normal for the area. The interdependence between climatic, hydrologic, geomorphic, ecological, and societal variables makes it difficult to adopt a definition that completely describes the drought phenomenon and associated impacts (Zeleke et al., 2017). Because of this, drought has several definitions; the central element is the deficit compared to the normal, or mean, amount of precipitation over an extended period such as a season, a year, or several years. Meteorological drought is characterized by a shortage of precipitation and represents a departure of precipitation from its climatological value calculated over a reference period.

Rainfall in the Horn of Africa is influenced by weather systems that develop in the Pacific Ocean, especially the central and east-central parts of the Pacific around the Equator. One of the main factors driving these systems is the temperature of the Pacific's surface, which affects the air pressure above the sea, and related wind and rainfall patterns across large areas of the tropics and sub-tropics. Relatively large changes in the sea's temperature create unusual weather patterns, such as drought or excessive rainfall and storms (Catley, Cullis, and Abebe, 2016).

While some research has been done concerning drought in Ethiopia, much of the work has focused on the meteorological predictive aspects, or macroeconomic impacts, rather than specific

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[1] In 2012, 1USD=17.78 Ethiopian Birr.

household impacts. Some of those studies determine specific causes of drought (Camberlin, 1997; Diro, Grimes, and Black, 2011) and others provide predictive algorithms for drought (Gissila et al., 2004). According to Camberlin (1997), monsoon activity over India is a major trigger for July–September rainfall variability in the East African highlands. A strong monsoon, depicted by low sea level pressure (SLP) anomalies in Bombay, corresponds to an increase in rainfall in the East African highlands, while weak monsoon conditions correspond to below-normal rainfall. Diro, Grimes, and Black (2011) investigate the relationship between global sea surface temperatures (SSTs) and rainfall in Ethiopia. Their finding shows that Ethiopian rainfall is negatively associated with both the Indian Ocean and Eastern Pacific SST. According to Diro, Grimes, and Black (2011), summer rainfall over the Ethiopian highlands is positively correlated with the equatorial East Pacific sea-level pressure and the southern oscillation index and negatively correlated with sea surface temperature (SST)[2] over the tropical eastern Pacific Ocean. High-positive SST (El Niño)[3] anomalies during the summer are associated with high drought probability over most of the agriculturally productive land and major water reservoir areas of Ethiopia (Degefu, 1987). All of this research indicates that excess rainfall tends to occur when there is a La Nina, and rain deficits occur when there is an El-Nino. Research by Gissila et al. (2004), focus on the development of a seasonal forecasting model for the Ethiopian summer rains using SST data for March, April and May in the Indian and Pacific Oceans. The research indicates that Ethiopian rainfall is highly variable, both temporally and spatially, and should be analyzed in clusters rather than as a whole. Incorporating Indian and Pacific SSTs in the March, April and May leading to the June, July, August, September (JJAS) rainy season can be used to develop a skillful forecast for part of Ethiopia. While improved rainfall predictions are critical for forecasting, developing drought indexes are also important for measuring relative deviations from expected precipitation.

Many definitions and related mathematical tools have been developed to measure drought. The most widely used mathematical tools developed are the Palmer Drought Severity Index (PDSI) (Palmer, 1965) and standardized precipitation index (SPI) (McKee et al., 1993). The PDSI is a soil moisture algorithm that includes terms for water storage and evaporation, whereas the SPI is a probability index based only on precipitation.

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[2] Sea surface temperature (SST) is defined as the temperature of the sea close to its surface.

[3] El Niño – a warming of the central Pacific Ocean leading to high-pressure weather systems.

The SPI, often called the Z-score (Khan, Gabriel, and Rana, 2008), is the number of standard deviations from the rainfall mean collected over a designated time period. For precipitation, high positive values correspond to wet periods and high negative values correspond to rain deficiency periods. McKee et al. (1993) used SPI as a classification system to define drought intensities. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI turns positive.

Wu et al. (2001) did an evaluation of the standard precipitation index (SPI), the China Z-Index (CZI), and the statistical Z-score. The result indicates that the Z-score can provide results that are statistically similar to SPI for all time scales. This is advantageous because the Z-score is relatively easier to compute. According to Wu et al. (2001), the Z-score does not require fitting the data to either the Gamma or Pearson Type III distributions and we therefore adopt the z-score methodology for our purposes. WMO (2012) provided a categorization of drought based Z-scores of rainfall as shown in Table 1. In order to construct appropriate drought indexes, we first determine typical seasonal rainfall patterns for appropriate seasonal aggregations.

Table 1: *Categorization of drought based on Z-score (SPI) values*

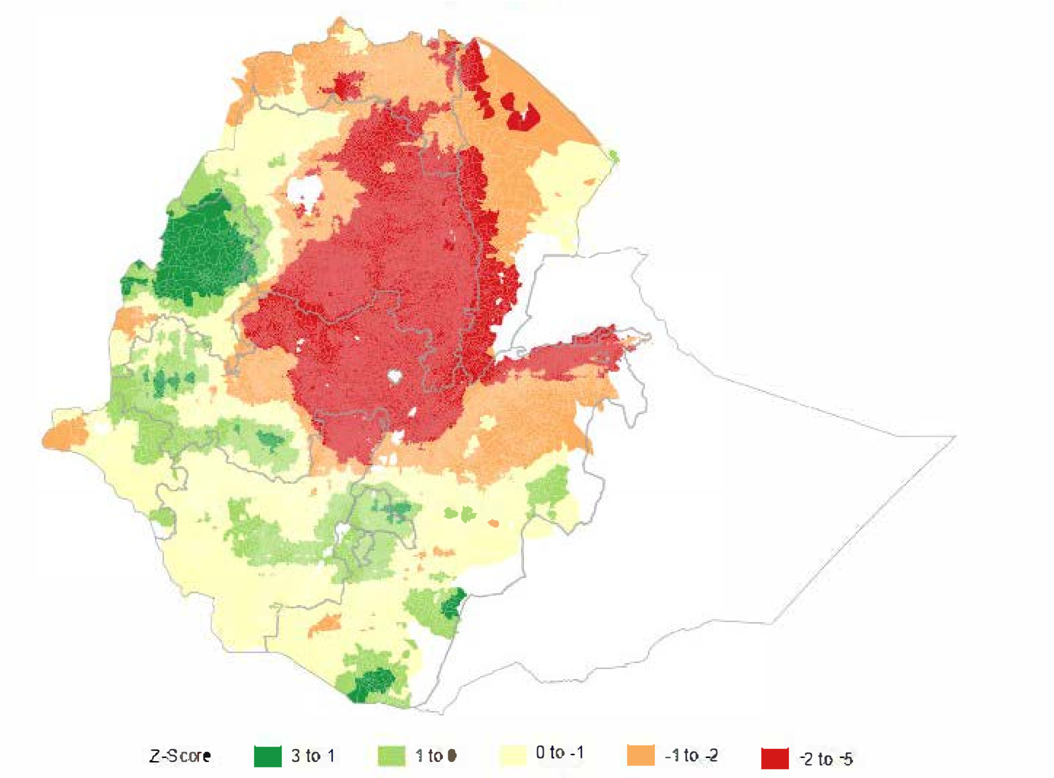
Z-score (SPI) values	Drought/wetness category
2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

Source: WMO (2012).

Ethiopia has two major rainy seasons. The *Belg* season generally lasts from February to May and provides rainfall for agriculture in central Ethiopia. About 10 percent of the Ethiopian population depend on the Belg rainy season (Degefu, 1987). The *kiremt* or *Meher* rains are more reliable and run from June to mid-September, providing conditions suitable for agriculture for most regions of the country. The *Meher* rains support 92 percent of total area cultivated and 97 percent of total crop production in the country (Taffesse et al., 2012). Hence, a rain failure during the *Meher* season can more substantially increase in food insecurity for those affected by the drought with broad adverse impacts on the rest of the economy.

In June 2015, Ethiopia's National Meteorological Agency (NMA) declared that the *Belg* rains had failed. Soon after, the *kiremt* rains were severely delayed and became erratic, directly affecting 9.7 million Ethiopians (Jjemba, Singh, and Arrighi, 2017). The drought areas were typically located in central and northern Ethiopia (Figure 1).

Figure 1: *Distribution of the 2015 drought: Rainfall deviation of* Meher *2015 from 15 years* Meher *average (2000-2014)*



Source: Authors' computation using the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) rainfall data.

Koo et al. (2019) analyzed the impact of the 2015 ENSO event on agriculture and the national economy of Ethiopia and found that Ethiopia's GDP fell by 1.6 percent with relatively higher losses experienced in the agricultural sector (agricultural GDP declined by 3.6 percent). Harvested area and crop yield also declined. For instance, the production of *teff*, which accounts for 22 percent of the cultivated area and is grown by 43 percent of all crop farmers (Hassen et al., 2018), fell by 7.3 percent. The 2015/16 drought also had a modest national impact on the animal herd size with specific locations suffering disproportionately. The 2015/16 drought was projected to increase national poverty by 1.2 percentage points (Koo et al., 2019), which is equivalent to an additional 656,200 people living below the poverty line. While these macroeconomic impacts provide a summary of the drought on the overall economy, we seek to explain the specific impacts on households disaggregated by access to irrigation.

Adoption of irrigation has been shown to increase food security and improve farm incomes (Ward, 2014). An agro-economic country-wide model to assess irrigation investments in both static and variable climate conditions over a 12-year simulation (2003-2015) by Block et al. (2008), determines that investments in irrigation can reduce the negative effects of drought and enhance production and farm income. Access to reliable irrigation reduces the risk of crop failure, and hence increases farmers' incentives to adopt new technologies and intensify cultivation, leading to increased productivity and greater returns from farming (Hussain and Hanjra, 2004).

While there are some research on how irrigation improves household food security in Ethiopia, it is more qualitative and descriptive in nature (Tesfaye et al., 2008; Mengistie and Kidane, 2016; Jambo, Alemu, and Tasew, 2021). As Jambo, Alemu, and Tasew (2021) studied, participation in small-scale irrigation increased daily calorie intake of the small-scale irrigation users by 644 kcal over non-user households. A second study determine that average food consumption expenditure per annual adult equivalent is about 74 percent higher for irrigation households (Tesfaye et al., 2008).

The few research papers looking at the role of small and medium scale irrigation affecting household food security and drought resilience in Ethiopia use small-sample cross sectional data which restricts relative robustness as well as quantitative methodology choices for analysis (Tesfaye et al., 2008; Mengistie and Kidane, 2016; Jambo, Alemu, and Tasew, 2021). For example, Tesfaye et al. (2008) apply Heckman's Two-step Estimation procedure and Jambo, Alemu, and Tasew (2021) use propensity score matching model (PSM) to analyze the impact of small-scale irrigation on household food security at local levels, which precludes some greater generalizability. Given our larger panel sample we can employ: (i) panel data collected from four main regions of the country (ii) employ a quasi-experimental difference-in-differences (DID) approach, (iii) which uses data collected before and during the ENSO event, (iv) and we explore more diversified outcome variables such as household dietary diversity score (HDDS), market participation, acreage response to drought, in addition to income and food and non-food expenditure that were done by others.

3 Data and Descriptive statistics

3.1 Data

The paper uses the Ethiopian Agricultural Commercialization Clusters (ACC) survey data collected by the International Food Policy Research Institute (IFPRI) in the four major regions of Ethiopia : Tigray, Amhara, Oromia, and the Southern Nations, Nationalities, and Peoples (SNNP). These four regions account for 86% of the population and more than 95% of the agricultural production in the country (Minot et al., 2021). The country was stratified by region and by ATA Agricultural Commercialization Clusters (ACC). A sample of households were selected from ACCs woredas and outside the ACCs woredas using systematic random sampling. The panel includes data for 2012 and 2016, covering a baseline and the ENSO drought shock period. The 2012 survey covers 3,000 households while the 2016 survey includes 4,991 households. A total of 2,752 households were interviewed in both rounds, and the descriptive and econometric analyses in this study are based on this balanced panel data.

The survey includes modules for household demographics, housing and assets, land ownership and use, crop inputs and labor use, crop production, storage and utilization, livestock ownership, sources of non-farm income, saving and credit, and food and non-food consumption expenditures. A separate module focuses on agricultural land use, including the size of agricultural parcel(s), and management and main water sources for agriculture. If the household uses either ground or surface water as the main source of water for the parcel, then the parcel is defined as irrigated. For our purposes, the household is designated as an irrigating household if it has at least one irrigated parcel.

The paper also uses the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) rainfall data, that provide decadal precipitation data (Funk et al., 2015). Monthly data are linked with sub-*kebele*[4] areas by pixel weights and are then summed to monthly averages. Households are linked into their sub-*kebele* using GPS coordinates of their homesteads. Z-scores are calculated as the difference of rainfall during the *Meher* season (June-September) of 2015 and the long-term 15-year *Meher* mean (2000-2014), and then divided by the standard deviation of the 15-year values. In this paper a household is defined as drought-affected when the Z-score is less than or equal to

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[4] *Kebele* is the lowest administration unit in Ethiopia and includes a few villages.

-1. According to McKee et al. (1993) a drought event occurs any time the standard precipitation index (SPI), also referred to as Z-score (Khan, Gabriel, and Rana, 2008), is continuously negative and reaches an intensity of -1.0 or less.

3.2 Descriptive statistics

Table 2 provides the economic and demographic characteristics of households at the baseline year of 2012 based on their exposure status to the 2015 ENSO drought event. We use baseline conditions because differences between 2012 and 2016 in time-varying variables could be a result of the drought. Households in sub-*kebeles* that were affected by the 2015 drought have slightly lower household size, are more likely to be female-headed, have somewhat older heads (by about 4.5 years), own less farm land (by about 0.6 hectares), and cultivated less land in 2012 (by about 0.5 hectares), compared to households who live in sub-*kebeles* that were not affected by the drought (Table 2). In addition, households in sub-*kebeles* affected by the 2015 drought were already poorer in 2012; they earned less net crop and total income, spend less on food and non-food expenditure, had a lower dietary diversity score, and sold a lower share of their harvest to the market (by 11 percentage points), compared to households in sub-*kebeles* that were not affected by the drought (Table 2).

The descriptive results in Table 2 suggest that the 2015 drought hit already poor communities, exacerbating existing socio-economic inequities. However, sub-*kebeles* affected by the 2015 drought were more likely to use irrigation than sub-*kebeles* unaffected by the drought (by about 4.7 percentage points) (Table 2). Irrigating households tend to perform better using several welfare measures. As shown in Table 3, a summary of economic and demographic characteristics of sampled households by irrigation status at baseline (2012) is depicted. Irrigating households have, on average, more household members, are more likely to be headed by a man, and own a slightly larger number of oxen and slightly greater education of the household head. Age of household head, farmland owned, and amount of land cultivated in the *Meher* season of 2012 were not statistically significantly different between irrigating and non-irrigating farmers. In terms of economic activity, households that used irrigation in 2012 had more income (both net crop income and total income) and had higher daily food and non-food expenditures than non-irrigators, sold approximately 11 percentage points more of their harvest and had a slightly higher household dietary diversity score. (Table 3).

Table 2: *Descriptive statistics at baseline by drought status*

	Household Affected by Drought			
	No	Yes		
	Mean	Mean	Mean Difference	P-value
Household size	6.00	5.44	0.557***	(0.000)
Ratio of male-headed households	0.91	0.82	0.0868***	(0.000)
Age of head (years)	43	48	-4.466***	(0.000)
Education of head (years)	3.28	3.06	0.221	(0.172)
Farmland owned (ha)	2.00	1.45	0.553***	(0.000)
Land cultivated in Meher	2.07	1.58	0.489***	(0.000)
Number of oxen owned	1.51	1.47	0.0413	(0.486)
Net crop income in Birr	14010	12982	1027.7	(0.140)
Total income in Birr	19677	17970	1707.0*	(0.034)
Daily food and non food expenditure (Birr)	37	31	5.549***	(0.000)
Daily non food expenditure (Birr)	13	9	3.544***	(0.000)
Daily food expenditure (Birr)	23	22	1.852*	(0.035)
Household dietary diversity score	6.18	5.60	0.580***	(0.000)
Share of harvest sold (%)	35.87	24.49	11.37***	(0.000)
Ratio of households who use irrigation	0.05	0.09	-0.0467***	(0.000)
Number of observations	1047	1705		

Note: stars reflect the level of significance, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: Author's calculation based on ACC data.

Table 3: *Descriptive statistics at baseline by irrigation status*

	Non-irrigators	Irrigators		
	Mean	Mean	Mean Difference	P-value
Household size	5.63	6.02	-0.398*	(0.010)
Ratio of male-headed households	0.85	0.90	-0.0477	(0.058)
Age of head (years)	46	45	0.856	(0.412)
Education of head (years)	3.09	3.74	-0.653*	(0.027)
Farmland owned (ha)	1.66	1.60	0.0558	(0.677)
Land cultivated in Meher	1.76	1.86	-0.106	(0.386)
Number of oxen owned	1.45	1.89	-0.432***	(0.000)
Net crop income in Birr	12741	20980	-8239.0***	(0.000)
Total income in Birr	17958	26588	-8629.6***	(0.000)
Daily food and non food expenditures	33	39	-6.714**	(0.001)
Daily non food expenditures	11	14	-3.004***	(0.000)
Daily food expenditure	22	26	-4.009*	(0.012)
Household dietary diversity score	5.80	6.07	-0.275**	(0.005)
Share of harvest sold (%)	27.74	41.53	-13.78***	(0.000)
Number of Observations	2541	211		

Note: stars reflect the level of significance, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: Author's calculation based on ACC data.

Table 4 depicts the number of irrigators and non-irrigators by survey rounds. From the 2,752 households sampled in both periods, 211 (7.7%) and 234 (8.5%) used irrigation in 2012 and 2016, respectively. The 2016 survey captures the production activities during the 2015 drought year as the survey is done through recall of the most recent production season. Of the 211 irrigating households in 2012, 104 did not irrigate in 2016. Conversely, 127 households who were not irrigating in 2012, were doing so in 2016. These changes in irrigation status might be linked to the 2015/16 ENSO event.

Table 4: *Number of households that use irrigation in two survey years*

Irrigation status	Irrigation status across years			
	0	1	2	Total
No irrigation	2414	0	0	2414
Irrigate only 2012	0	104	0	104
Irrigate only 2016	0	127	0	127
Irrigate in both years	0	0	107	107
Total	2414	231	107	2752

Source: Author's calculation based on ACC data.

As discussed in section 2, the value of Z-score less than or equal to -1 is used in this analysis as a cutoff point to identify drought affected households. Based on this criterion, among the 2752 households, 1705 (62%) were affected by the 2015 ENSO drought (Table 5). In addition, among the 211 households that used irrigation in 2012, 161 households (76%) were affected by the 2015 ENSO drought (Table 5).

Table 5: *Household affected by 2015 drought by irrigation status*

	Household affected by 2015 drought		
Households use irrigation in 2012	No	Yes	Total
No	997	1,544	2,541
	(39%)	(61%)	(100%)
Yes	50	161	211
	(24%)	(76%)	(100%)
Total	1,047	1,705	2,752
	(38%)	(62%)	(100%)

Source: Author's calculation based on ACC data.

For the most part, sampled irrigating and non-irrigating households are clustered in extremely dry, severely dry, moderately dry, and near normal drought intensities in 2012 (Table 6). Only 36 households belonged to moderately wet or greater rainfall condition in 2015.

Table 6: *Distribution of irrigators and non-irrigators by drought intensity*

	Drought intensity					
	Extremely Dry	Severely Dry	Moderately Dry	Near Normal	Moderately Wet	Total
No irrigation	683	458	277	960	36	2414
Irrigate only 2012	39	20	12	33	0	104
Irrigate only 2016	55	38	15	19	0	127
Irrigate in both years	36	35	19	17	0	107
Total	813	551	323	1029	36	2752

Source: Author's calculation based on ACC data.

3.3 Outcome Variables

The main outcome variables included in this study are net crop income (in real 2012 prices), cultivated area, average daily food expenditure (in real 2012 prices), household dietary diversity score (HDDS), and level of commercialization (measured as the ratio of harvest sold to total harvest). Table 7 depicts descriptive statistics of the outcome variables for non-irrigating households by drought status. As compared to irrigating farmers,non-irrigating households that were affected by the 2015 ENSO drought have faced lower net crop income (by 6,397 Ethiopian Birr), cultivated less land (by 0.52 hectares), reduced their daily food expenditure by 3.6 Birr, faced a reduced household dietary diversity score (by 0.7), and sold less of their output (by 16 percentage points).

Table 7: *Outcome variables for non-irrigating households by drought status in 2016*

Non Irrigators				
	Household affected by drought			
Variables	No	Yes		
	Mean	Mean	Mean Deference e	P_value
Net crop income in Birr	18225	11828	6396.9***	(0.000)
Land cultivated in *Meher*	2.13	1.61	0.517***	(0.000)
Total daily food expenditure	63	59	3.564*	(0.042)
Household dietary diversity score	6.54	5.83	0.708***	(0.000)
Share of crops sold (%)	38.75	23.02	15.73***	(0.000)
Number of observations	1011	1507		

Note: stars reflect the level of significance, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: Author's calculation based on ACC data.

Table 8 shows how the 2015 drought affected irrigating households. Among irrigating households, the drought led to a reduction in cultivated area (by 0.57 hectares), in the household dietary diversity score (by 0.54), and in the share of harvest sold (by 14 percentage points) (Table 8). Importantly, net crop income and daily food expenditures were not significantly different between households that were affected and those that were not affected by the drought.

Table 8: *Outcome variables for irrigating households by drought status in 2016*

Irrigators				
	Household affected by drought			
Variables	No	Yes		
	Mean	Mean	Mean Difference	P_value
Net crop income in Birr	28382	21121	7260.8	(0.078)
Land cultivated in Meher	2.27	1.7	0.565*	(0.045)
Total daily food expenditure	85.7	80.1	5.575	(0.546)
Household dietary diversity score	6.75	6.21	0.543*	(0.014)
Share of crops sold (%)	56.77	42.96	13.82**	(0.007)
Number of observations	36	198		

Note: stars reflect the level of significance, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: Author's calculation based on ACC data.

The descriptive results so far have indicated that the 2015 ENSO drought disproportionately affected areas that were already less productive, and adversely affected the welfare of both irrigating and non-irrigating households, albeit to a different extent. However, baseline differences derived from the descriptive statics between areas affected and not affected by the drought and between those households with and without irrigation makes it difficult to distinguish the impact of the drought from general trends of the outcome variables and whether the drought had heterogeneous impacts by irrigation status. In the sections that follow, we will approach the question using econometric methods that allows us to establish causal linkages between the 2015 drought and the outcomes of interest in a manner that allows for baseline differences and common trends.

4 Empirical Model

The econometric approach exploits the exogenous ENSO drought shock of 2015 that hit large parts of central and northern Ethiopia. The data collected from the same households in 2012 (before the drought) and in 2016 (after the drought) allows us to employ a quasi-experimental difference-in-differences (DID) approach to analyze the impact of the 2015 drought on several household welfare measures. The household welfare measures include, amount of land brought into cultivation, real net crop income (in 2012 real prices), real total daily food expenditure (in 2012 real prices), share of harvest sold, and household dietary diversity score.

Equally as important as understanding the impact of the 2015 ENSO event on the selected welfare measures, is the role access to irrigation plays to withstand the adverse effects of the drought. Irrigation is expected to provide several opportunities for farmers to cope with the drought shock. These opportunities include, but are not limited to, the provision of water for supplemental irrigation in the main rainy season, providing farmers more flexibility in crop choices based on availability of land and water resources, and enabling farmers to leverage their harvest and crop income from their irrigation season to invest in the rainy (*Meher*) season production.

The canonical 2x2 DID method that can be used to estimate the effect of the drought is represented in equation 1 below.

$$Y_{it} = \alpha + \beta_1 D_i + \beta_2 T_t + \beta_3 T_t * D_i + \epsilon_{it} \tag{1}$$

where Y_{it} is the outcome of interest of household i in year t; D_i is a treatment indicator showing whether household i is affected by the 2015 drought; T_t is a time indicator for 2012 vs 2016; and ϵ_{it} is a statistical noise term.

The specification in equation 1 does not allow for treatment heterogeneity. The effect of the drought, however, is likely to differ by households' access to irrigation, which is a principal component of this study. The model that allows for heterogeneous effects of the drought by irrigation status is provided as:

$$Y_{it} = \alpha' + \beta_1' D_i + \beta_2' T_t + \beta_3' T_t * D_i + \beta_4' I_i + \beta_5' I_i * D_i + \beta_6' I_i * T_t + \delta_0' I_i * D_i * T_t + \epsilon_{it}' \qquad (2)$$

where Y_{it}, D_i, T_t, and ϵ_{it} are as defined in equation 1 and I_{it} shows whether household i had access to irrigation at baseline (in 2012). The DID estimate of the effect of the 2015 drought on the outcome variables among non-irrigating households is β_3', while this effect among irrigating households is given by $\beta_3' + \delta_0'$.

The parallel trends assumption in equations 1 and 2 states that, in the absence of the drought, the evolution of the outcome variables among all households affected by the drought is, on average, the same as the evolution of the outcome variables among households that are not affected by the drought. However, it is possible for baseline differences in household characteristics such as household size, gender of the head of the household head, age of the head of the household, and the size of farmland owned as shown in Table 2 to lead to different trajectories of the outcome variables over time. A less stringent assumption is, therefore, to allow a parallel trend assumption conditional on baseline differences of these household characteristics. For instance, the parallel trend assumption may hold within male-headed or within female-headed households but not necessarily across all households. That is, the evolution of the outcome variables over time may vary for female vs male headed households, small vs large farm sizes, older vs younger households, and small vs larger household sizes.

The estimation of the conditional DID that allows the parallel trend assumption after controlling for baseline differences is done using doubly robust DID as suggested by Sant'Anna and Zhao (2020) and Callaway and Sant'Anna (2021). This estimator makes use of a logistic propensity score model for the probability of being in the treated group, and of a linear regression model for the outcome evolution among the comparison units, where only either the propensity score or the outcome regression model needs to be correct.

The parameter of interest in all these estimations above is the average treatment effect on the treated (ATT), which, in our context, refers to the effect of the drought on those households affected by the drought. In all the estimations, the standard errors are bootstrapped using the multiplier bootstrap procedure detailed in Callaway and Sant'Anna (2021) that ensures that there are always observations from each group in each bootstrap draw, which solves the problem of traditional empirical bootstrapping that can affect the structure and distribution of treatment and control groups as there may be no observations from a particular group in some bootstrap iterations. However, the multiplier bootstrap standard errors, which are from draws that are not cluster-specific, may not fully account for the effects of geography-based clustering and can influence the study's conclusions.

5 Results

Table 9 presents the DID results on the impact of the 2015/16 drought in Ethiopia on those households affected by the drought without considering potential heterogeneity of these effects based on different characteristics of farmers. The result shows that the drought caused farmers' net crop income to drop by 35 percent (4,522 Ethiopian Birr in real 2012 prices) and has led to a 2.8 percentage point reduction in the share of harvest sold to the market. Although the results in Table 9 indicate that the drought has led to declines in cultivated area and household dietary diversity scores along with an increase in average daily food expenditures, these results are not statistically significantly different from zero. As shown below, these results change when we include heterogeneity of the effects of the drought by irrigation status and when we allow the assumption of parallel trend conditional on household covariates.

Table 10 shows the results of the DID estimation with the effect of the drought allowed to vary by access to irrigation as shown in equation 2. The drought caused a 37 percent reduction in net crop income (4,242 Ethiopian Birr in real 2012 prices) for rainfed households that were affected by the drought. On the other hand, the effect of the drought on net crop income of irrigating farmers affected by the drought is not statistically significantly different from zero. Irrigators affected by

Table 9: *Average effect of the drought on those affected by the drought (ATT) without considering heterogeneity of effects*

Outcome variable	ATT	Standard error
Net crop income (Birr in real 2012 prices)	-4522.66***	1012.56
Cultivated area (hectares)	-0.022	0.061
Average daily food expenditure (Birr in real 2012 prices)	0.612	1.967
Household dietary diversity score	-0.099	0.066
Percent of harvest sold	-2.764**	1.226
Number of observations	5076	422

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Source: Author's computations.

the drought increased their average daily expenditures on food by 65 percent (21 Ethiopian Birr in real 2012 prices). The impact of the drought on average daily food expenditure is not statistically significantly different from zero for non-irrigating farmers. In addition, the drought has led to a reduction of rainfed households' dietary diversity score by 0.12, while drought-affected irrigators managed to maintain their diet diversity. The drought has also led to a three percentage point reduction in the share of harvest sold by non-irrigating drought-affected households. However, the drought did not reduce the share of harvest sold by irrigating households.

Table 10: *Average effect of the drought on those affected by the drought (ATT) with heterogeneous effects by irrigation status*

Outcome variables	ATT on non-irrigators	ATT on irrigators
Net crop income (in real 2012 prices)	-4241.91***	-3244.43
	(1059.7)	(3297.8)
Cultivated area	-0.011	-0.022
	(0.063)	(0.187)
Average daily food expenditure (in real 2012 prices)	-1.045	21.112**
	(2.2)	(8.4)
Household dietary diversity score	-0.12*	0.306
	(0.065)	(0.273)
Percent of harvest sold	-2.999**	5.798
	(1.269)	(6.502)
Number of observations	5076	422

Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Source: Author's computations.

Table 11, our preferred model, provides results from the DID estimate where the parallel trend assumption is expected to hold conditional on household size, gender of the household head, age of the head of the household, and the size of farmland owned at baseline. The result shows that the drought caused a 37 percent reduction in net crop income (4,250 Ethiopian Birr in real 2012 prices) for those drought-affected households without irrigation, while the effect of the drought on irrigators was statistically insignificant. Therefore, non-irrigators lost more than one-third of their net crop income as a result of the drought, while for irrigators, the impact was not statistically different from zero.

Unlike the previous model that assumes a strong parallel trend assumption, the results in Table 11 have shown that non-irrigating farm households had to reduce the amount of land that they cultivate by eight percent (0.12 hectares), while the effect of the drought on the size of land cultivated is statistically insignificant for irrigators. In addition, Table 11 shows that irrigators affected by the drought were able to raise their daily expenditures on food by 72 percent (23 Ethiopian Birr in 2012 real prices), which allowed them to maintain their household dietary diversity score.

The household dietary diversity of non-irrigators affected by the drought declined by 0.17 (Table 11), as these farmers experienced a sharp decline in net crop income and were not able to increase their daily expenditures on food. The average household dietary diversity score of non-irrigating farmers before the drought was 5.5. Thus, the drought accounts for a 3 percent reduction in the HDDS. However, given that their HDDS was already very small (5.52 in a score that ranges from 0 to 12), any reduction in diet diversity represents a worsening condition of the households' economic access to food.

The results in Table 11 also showed that the share of harvest sold by non-irrigators affected by the drought dropped by 2.1 percentage points, while the effect of the drought on marketed share of irrigators is not statistically significantly different from zero. The 2.1 percentage point reduction in the share of harvest sold due to the drought by non-irrigating farmers amounts to a 10 percent reduction in the average share of harvest sold by these farmers before the drought. The impact of the drought on market participation is accentuated by the fact that the drought affected households were already selling 11 percentage points less than households in areas not affected by the drought in pre-drought conditions in 2012 as shown in Table 2.

Table 11: *DID with parallel trend conditional on covariates*

Outcome variables	ATT on non-irrigators	ATT on irrigators
Net crop income (in real 2012 prices)	-4249.75***	-2986.87
	(1070.36)	(3044.54)
Cultivated area	-0.123**	-0.025
	(0.054)	(0.18)
Average daily food expenditure (in real 2012 prices)	0.574	23.36***
	(2.01)	(7.84)
Household dietary diversity score	-0.171**	0.283
	(0.07)	(0.28)
Percent of harvest sold	-2.145*	3.487
	(1.40)	(6.16)
Number of observations	5076	422

Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Source: Author's computations.

6 Severe and extreme drought

Although we followed the existing literature to define drought as a Z-score of less than -1, described in section 2, the severity of the 2015 drought indicates the use of a more restrictive definition of drought including Z-scores less than -1.5 or -2, which excludes areas hit by moderate drought. A Z-score of rainfall of less than -1.5 will cover areas hit by severe and extreme drought as indicated in Table 1. However, it is to be noted that in our sample, irrigators account for only 8 percent of the total observations. Given that our main interest is in identifying the heterogeneous effect of the drought by irrigation status, the use of -1.5 Z-scores will reduce the number of households defined as affected by drought, and hence the number of irrigators affected by drought. As such, if we define drought only to refer to severe and extreme droughts, the ATT will be estimated with less precision (high standard errors). We present the results of this estimation in Table 12.

As expected, the ATT in Table 12 are estimated with less precision as compared to Table 11. Yet, we still see that the extreme drought caused a reduction in net crop income (of 2,605 Ethiopian Birr in real 2012 prices) for farmers without irrigation, a loss that amounts to 16 percent of their pre-drought net crop income. As before, the impact of the drought on irrigating farmers is not statistically significantly different from zero (Table 12). The results also indicate that irrigators affected by the drought increased their daily food expenditures by 85 percent (27.5 Birr in real

2012 prices), a result qualitatively similar to that in Table 11. Severe and extreme drought required non-irrigators affected by the drought to increase their daily food expenditure by 17 percent (5 Birr in real 2012 prices). The imprecise estimates in Table 12, that resulted from further slicing of a small fraction of irrigators in the sample, resulted in statistically insignificant results on the effect of the drought on cultivated area, HDDS, and share of harvest sold.

Table 12: *DID with parallel trend conditional on covariates when drought is defined with Z-score less than -1.5*

Outcome variables	ATT on non-irrigators	ATT on irrigators
Net crop income (in real 2012 prices)	-2605.7***	-3917
	(976.6)	(2781.7)
Cultivated area	-0.074	-0.057
	(0.056)	(0.17)
Average daily food expenditure (in real 2012 prices)	5.05***	27.50***
	(1.94)	(6.99)
Household dietary diversity score	-0.054	0.14
	(0.076)	(0.27)
Percent of harvest sold	-0.985	-1.797
	(1.32)	(5.70)
Number of observations	5076	422

Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: Author's computations.

7 Conclusions and Policy Implications

The results from this quasi-experimental study have two major takeaways. First, perhaps unsurprisingly, the 2015 ENSO drought event that hit most of the northern and central parts of Ethiopia has led to significant reductions of net crop income, share of harvest sold, size of land cultivated, and households' diet diversity for rainfed farmers affected by the drought.

Second, the drought has heterogeneous effects by irrigation status as households with access to irrigation have managed to withstand the adverse effects of the drought. Irrigators, subjected to the drought, maintained their cultivated area, which helped them retain their net crop income. They were also able to spend more on daily food expenditures, which allowed them to maintain dietary diversity in the household. The results confirm that irrigation is a key climate smart agricultural intervention that can improve the resilience of farming households in the face of major weather shocks such as the 2015 ENSO drought.

The results call for expansion of irrigation investments in Ethiopia as an important source of resilience. It reaffirms the recent focus of the Government of Ethiopia to expand irrigation in the country, which had only reached around 5 percent of its potential. In addition, the findings on the role of irrigation as a resilience measure for drought applies for a number of African countries facing climate change and weather variability shocks. Sub-Saharan Africa (SSA) can expand irrigation with substantial increases in net revenues from agriculture that can benefit millions of farm households in rural Africa. Xie et al. (2014) determined that SSA has a large potential for the expansion of smallholder irrigation. Using motor pumps as an example, SSA has the potential to expand irrigated area by 30 million hectares with a net revenue increase of $22 billion annually for an estimated 185 million rural households. Xie et al. (2014) also estimated 24 million hectares of irrigable land in Africa using treadle pumps, 22 million hectares of irrigable land using small reservoirs, and 20 million hectares of irrigable land using communal river diversions. The results of this study add to the strong resilience effect of irrigation during major droughts and calls for a renewed attention and commitment to the development of irrigation in Africa, not only to increase production and income but also to make African agriculture resilient to adverse weather shocks.

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