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Is it the Climate or the Weather? Differential Economic Impacts of Climatic Factors in Ethiopia

Mintewab Bezabih, Salvatore Di Falco, and Alemu Mekonnen[*]

Abstract

This paper assesses the distinct impacts of weather and climate change measures on agricultural revenue of farm households in the Amhara region of Ethiopia. This distinction is highlighted by observations in the temperature data, which show that the pattern of temperature for both short term and long values follows a bell-shaped distribution, with the striking feature that the extreme ends of the distribution have fatter tails for the long term values. The analysis employs monthly rainfall and 14 temperature categories related to weather measures and four categories corresponding with the extreme ends of the long term temperature distribution. The analysis also distinguishes between summer and spring seasons and different crops in recognition of Ethiopia's is a multi-cropping and multi-season agriculture. The major findings show that temperature effects are distinctly non-linear but only when the weather measures are combined with the extreme ends of the distribution of the climate measures. In addition, rainfall generally has less important role to play than temperature, contrary to expectations in rain-fed agriculture.

Key Words: crop revenue; climate change; weather variability; Mundlak's Fixed Effects method; Ricardian analysis; Ethiopia
JEL Codes: D2, Q12, Q15

Introduction

Agriculture is the economic sector that is most directly linked to climate and climatic change. The empirical estimation of the role of climatic factor on agricultural outcomes is however, subject to considerable controversy (Mendelsohn et al., 1994; Deschênes and Greenstone, 2007; Fisher et al. 2012). The controversy is (mostly) based on two important related issues: the choice of the model and the choice of climatic factors metrics. Since the pioneering contribution of Mendelsohn et al. (1994), the use of the *Ricardian* model has been adopted widely. This is a hedonic approach that uses cross-sectional analysis where farmland values or farm net revenues are regressed on long term average climate variables. This approach has the key advantage that it can take account for all the range of different adaptation measures that farmers may put in place (Lang, 2007). It has, however, been criticized on the ground of potential inconsistency of parameters estimated by cross sectional analysis. There may be unobservable confounding factors (e.g., soil quality) that affect the outcome variable. The use of the *Ricardian* approach can therefore suffer by omitted variables bias. To circumvent this problem random year-to-year weather variation in a panel can be used to estimate the relationships between agricultural profits or yields and weather (Deschênes and Greenstone; 2007; Schlenker and Roberts; 2009).[1] While, this strategy has clear econometric benefits it does use short - term variation (annual weather)[2] to estimate the impact of a long -term phenomena (climate). The difference matters as using inter-annual changes in weather can only capture a limited set of adaptation measures implemented by farmers (Massetti and Mendelsohn, 2011). The use of year-to-year weather fluctuation is, thus, likely to produce larger estimates of the impact of climate change in agriculture (Deschênes and Greenstone, 2007).[3]

The contribution of this paper is twofold. First, we contribute to the literature and try to solve the controversy by using a simple but comprehensive empirical strategy. We use a panel data model where the inclusion of time-invariant (e.g., climate) variables along with time variant (weather) is accommodated and that allows for correlation between time invariant variables and the fixed effect. We therefore use the Mundlak-Krishnakumar estimator (Mundlak, 1978; Krishnakumar, 2006).[4] This is the first paper

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[1] Schlenker and Roberts (2009) argue that estimating the correct relationship between weather and yields is a critical first step before assessing structural shifts in response to climate change.

[2] Assessing the impacts of weather-related measureson agricultural yields has been a commonplace in the agronomic literature (e.g. Black, 1978; Adams, 1995;Brown and Rosenberg, 1999; Cassman, 1999; Merns et al., 2001;Dai et al.2004;Murthy, 2004; Yu, 2011)

[3] The readers interested in the identification of the adaptation strategies should refer to Kurukulasuriya and Mendelsohn, 2008; Seo and Mendelsohn, 2008a; Seo and Mendelsohn, 2008b; Di Falco and Veronesi, 2013.

[4] For an application in the education sector see Chatelain and Rolf (2010).

that attempts to estimate the role of both weather and climate on economic outcomes. The inclusion of both climate and weather allows capturing the full extent of underlying adaptation decisions. Farmers may indeed respond to both long run changes as well as weather shocks. Indeed, there is a wealth of evidence, particularly from developing countries, showing that weather variability could lead to non-negligible changes in farming practices, as a form of adaptation. In line with this, Burgess et al. (2013) show that weather fluctuations have a profound effect on the health and mortality of India's rural population, through its effect on agricultural production. As adaptation is implicitly an important feature of the Ricardian approach (Massetti and Mendelsohn, 2011), omission of the short- term impacts – such as weather shocks that trigger an adaptive response - implies that the approach would produce biased estimates.[5] We use information on both temperature and rainfall.[6]

Secondly, this paper focuses on assessing the impacts of weather and climate on agriculture in Ethiopia by incorporating the different features of short term (weather) and long term (climate) measures and emphasizing on extreme values corresponding to the measures.[7] We follow Schlenker and Roberts (2006; 2009) and use the full information on the distribution of both long run and short run temperature. As Hodges (1991) and Grierson (2002) show, plant growth depends on the cumulative exposure to heat and precipitation during the growing season. Specifically, as plants cannot absorb heat above or below a specific threshold, the effect of heat accumulation tends to be nonlinear. As a result, the standard agronomic approach involves converting daily temperatures into degree days, which represent heating units accounting for such non-linarites. Rosenzweig et al. (2009) argue that due consideration should be given to disproportionately large changes in the frequency of extreme events that are associated with, and not captured by, small changes in long term mean temperatures. Indeed, the

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[5] This distinction between short term and long term climate measures is highly relevant in a setting like Ethiopia, where both seasonal and yearly variations in rainfall are significant, rainfall is hugely erratic and weather insurance mechanisms are virtually nonexistent (Dercon et al., 2009; Adnew, 2006), leaving considerable rooms for weather related adaptations.

[6] Furthermore, unlike many climate change studies that have focused on estimating the impact of either temperature or precipitation in isolation, we combine both measures in our analysis. As argued in Auffhammer et al. (2013) such an approach is crucial to in order obtain unbiased estimates of the effects of changes in precipitation and temperatures, which are historically correlated, both variables must be included in the regression equation, especially if the correlation is predicted to change in the future.

[7] The difference between weather and climate is a measure of time. While weather is the day-to-day state of the atmosphere, and its variation over minutes to weeks, climate is defined as statistical weather information that describes the variation of weather at a given place for a specified interval. To determine climate, the weather of a locality is usually averaged over a 30-year period (Gutro, 2005). Weather and climate are expected to have different economic implications, as they represent essentially different phenomena (Fischer et al, 2012). It should also be noted that to the extent that the distributions of weather and climate are identical, the distinction between the two is irrelevant. The essence of such distinction becomes relevant when the two are distributionally different.

effects of such variations and extremes are likely to be captured through measures that account for changes in patterns of temperature in a more detailed manner, as opposed to average climatic parameters (De Salvo et al., 2013). In addition, Maraun et al. (2010) show that extreme events and temporal-spatial variations tend to be poorly represented by average climate change measures. We use panel data from Ethiopia (four rounds from 1999 to 2007) combined with 30-year monthly rainfall and temperature data. Moreover, the country provides a large extent of variation in climatic factors. We distinguish between summer and spring seasons and different crops in recognition of Ethiopia's multi-season agriculture.

Long term mean measures are used as climate variables, while the weather variables were constructed as averages for the years corresponding to the survey years. Ethiopia is a prime area to study the impact of climatic factors on agriculture. The country heavily relies on the agricultural sector and like many other sub Saharan countries is expected to suffer large part of the impact of climate change (Mendelsohn et al. 2006). Developing countries and their economic progress are likely to suffer tremendously from climate change, given their extremely nature-dependent agrarian economies (Mendelsohn and Dinar, 2009). As a result, accurate quantification of the economic impact of climate change on the agricultural sector is of paramount importance in guiding appropriate adaptation measures (Sachs et al., 1999; Stage, 2010) and ensuring genuine participation of developing countries in climate change agreements (Cao, 2008; Timmins, 2006).

We find that the distribution of weather temperature and climate temperature, measured in terms of number of days spent in each degree range over a growing season, indicates that both follow a bell-shaped distribution across the -5 to +40 degree range. However, both ends of the extreme values exhibit a fatter tail for the distribution of climate temperature to the weather temperature distribution. We also find that long-term impacts are larger than short term. This may indicate that farmers, contrary to what is assumed by the *Ricardian* framework, are not adapting optimally to climate change. While, they may have better capacity to cope with weather variability.

The rest of the paper is organized as follows. The next section presents an overview of the importance of climate change and weather uncertainty in Ethiopia. Next, the data employed in the empirical analysis is presented. The econometric methodology employed is discussed in the section that follows. The empirical findings are then discussed, and the last section concludes the paper.

Weather variability, climate change and agricultural productivity in Ethiopia: a Background

Agriculture remains one of the most important sectors in the Ethiopian economy for the following reasons: (i) it directly supports about 83% of the population in terms of employment and livelihood; (ii) it contributes over 40% of the country's gross domestic

product (GDP); (iii) it generates about 85% of export earnings; and (iv) it supplies around 73% of the raw material requirements of agro-based domestic industries, such as biofuels (MEDaC 1999; AfDB 2011). It is also the major source of food for the population and hence the most important sector for food security. In addition, agriculture is expected to play a key role in generating surplus capital to speed up the country's overall socio-economic development (MEDaC 1999).

Ethiopia has a population of over 80 million with a population growth rate of about 2.6% (AfDB 2011). The country has a total land area of about 112.3 million hectares. Of this, about 16.4 million hectares are suitable for producing annual and perennial crops. Of the estimated arable land, about eight million hectares is used annually for rain-fed crops. Small-scale farmers who are dependent on rain-fed mixed farming dominate the agricultural sector; they use traditional technologies with low inputs and get low output. The present government of Ethiopia has given top priority to this sector and has taken steps to increase its productivity. However, various problems are holding this back. Some causes of poor crop production are declining farm size; subsistence farming partly due to population growth; land degradation due to inappropriate land use such as cultivation of steep slopes; over cultivation and overgrazing; and inappropriate policies. Other causes are tenure insecurity; weak agricultural research and extension services; lack of appropriate agricultural marketing; an inadequate transport network; low use of fertilizers, improved seeds and pesticides; and the use of traditional farm implements. However, the major causes of low levels of production are drought, which often causes famine, and floods. This climate related disasters make the nation dependent on food aid.

With agriculture almost completely dependent on rainfall, rain rules the lives and well-being of many rural Ethiopians. It determines whether they will have enough to eat and whether they will be able to provide basic necessities and earn a living. Indeed, the dependence on rainfall and its erratic pattern has largely contributed to the food shortages and crop crises that farmers are constantly faced with. Even in good years, the one-time harvest or crop may be too little to meet the yearly household needs; as a result, the majority of Ethiopia's rural people remain food insecure (Devereux 2000)[8].

Rainfall contributes to poverty both directly, through actual losses from rainfall shocks, and indirectly, through responses to the threat of crisis. The direct impacts most often occur when a drought destroys a smallholder farmer's crops. Under such circumstances, not only will the farmers and their families go hungry, but they also will

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[8]Ethiopia has experienced at least five major national droughts since 1980, along with literally dozens of localized ones (World Bank 2008b). These cycles of drought create poverty traps for many households, constantly consuming any build-up of assets or increase in income. Evidence shows that about half of all rural households in the country experienced at least one major drought during the five years preceding 2004 (Dercon, 2009). The evidence also suggests that these shocks are a major cause of transient poverty. That is, had Ethiopian households been able to smooth consumption, then poverty in 2004 would have been at least 14 percent lower, which translates into 11 million fewer people falling below the poverty line.

be forced to sell or consume their plough animals in order to survive. They are then significantly worse off than before because they can no longer farm effectively when the rains return (Barrett et al., 2007).

Data and variables

Data used in the analysis were collected through four waves of rural household surveys conducted in the years 2000, 2002, 2005 and 2007 with the same households. The surveys were conducted by the Ethiopian Development Research Institute and Addis Ababa University in collaboration with Gothenburg University, and through financial support from the Swedish International Development Cooperation Agency (Sida). The survey sites include households in two Zones (South Wollo and East Gojjam) of the Amhara National Regional State, a region that encompasses part of the Northern and Central Highlands of Ethiopia.

Monthly rainfall and daily temperature data were obtained from the Ethiopian Meteorology Authority, in eight stations close to the study villages (*kebeles)* for the years 1976 to 2006. In order to impute farm specific information from station level observations, an inverse distance weighting interpolation method was employed. This method combines latitude, longitude, and station level rainfall and temperature observations. The climate change and weather measures used in the analysis are then constructed from these rainfall and temperature data[9].

Temperature and rainfall variables

Following Schlenker and Roberts (2006; 2009), we construct the distribution of temperature by first fitting a sinusoidal curve between predicted minimum and predicted maximum temperatures. This sinusoidal interpolation gives the time spent in each 1◦C-degree temperature interval between –5◦C and +40◦C within each day[10]. Each of the one degree Celsius in the -5 to 40 degree Celsius range is then converted into a more aggregate distribution by summing together each three-degree temperature interval. The length of time spent on each three-degree Celsius temperature interval in each day is then summed across all days of the month, for each farm household.

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[9]There are two instances where the assessment of weather as a separate variable may not be important. First, to the extent that weather variability is stable over time, it may also mimic climate change, making the impact of climate change on agricultural productivity akin to that of weather variability. Second, if mechanisms are in place to ensure against weather risks, then farmers are unlikely to incorporate much of the impact of weather variability into their decision making.

[10] The determination of the maximum and minium values of the range is based on our observed data.

Given seasonality of rainfall and cropping patterns in Ethiopian agriculture, further aggregation of the temperature distribution is done for the minor and major rainy seasons, instead of an aggregate growing season used in much of the literature[11]. The spring (*Belg*) includes the months between March and May, while the summer (*Kiremt*) months are between June and September. Accordingly, spring temperature distribution is comprised of the total sum of the monthly values for each three degree interval over the spring months, and the summer temperature distribution will be the summation of the values over the spring months, corresponding to each survey year.

The long term seasonal temperature distribution is obtained by averaging the three-degree range distribution over the 30 years, for each season. The seasonal rainfall measure is the sum total of monthly rainfall values for the months in the corresponding season, for each survey year.

Table 1 shows the frequency distribution of temperature variables corresponding to the survey years and over the long term. As would be expected, the pattern of temperature over the three degree ranges follows a bell-shaped distribution, with many of the days spent in the 10-30 degree ranges. This holds true for both yearly and long term mean distributions. What is striking, however, is the fact that the extreme ends of the distribution have unequal values for the short and long term mean temperature, highlighting the need to include the extreme long term temperature values in our analysis along with the short term (weather-based) temperature measures[12].

Table 1: Distribution of summer and spring temperature values over the short and long term

	Spring temperature					Summer temperature				
	1999. 000	2001. 000	2004. 000	2006. 000	long term average	1999. 000	2001. 000	2004. 000	2006. 000	long term average
temperature (<1°C)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0. 000	0.000	0.000
temperature (1°C-3°C)	1.019	1.000	1.000	1.001	1.039	1.026	1.223	1.000	0.983	1.055
temperature (4°C-6°C)	0.067	0.000	0.034	0.004	0.100	0.083	0.249	0.000	0.000	0.151

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[11]In studies from the United States, the convention is to include the months of January, April, July, and October (see, e.g., Deschenes and Greenstone, 2007; Schlenker and Roberts, 2006;2009).

[12] In order to highlight the significant differences across villages with respect to temperature, Appndeix C and D present a t-test on the distribution of temperature values between a selected kebele, Amanuel, and all other kebeles. In addition, the presence of signficant differences in access to infrastructure across kebeles is presented in Appendix B.

temperature (7℃-9℃)	1.136	0.021	0.342	0.279	0.372	1.471	0.970	0.000	0.000	0.361
temperature (10℃-12℃)	5.206	1.359	2.037	2.257	2.100	4.984	3.0 50	1.362	1.181	1.789
temperature (13℃-15℃)	15.569	17.517	11.605	15.350	14.813	16.992	15.842	18.327	16.536	17.630
temperature (16℃-18℃)	15.605	17.084	18.040	17.847	17.570	19.459	20.239	18.551	19.976	19.046
temperature (19℃-21℃)	10.747	10.989	11.111	10.859	11.125	17.913	18.214	16.048	17.807	17.143
temperature (22℃-24℃)	12.722	14.359	12.367	14.302	13.425	11.382	14.824	16.468	14.717	14.566
temperature (25℃-27℃)	13.925	17.107	15.770	18.148	16.017	10.144	9.228	11.236	10.090	10.210
temperature (28℃-30℃)	11.199	10.147	14.899	9.388	11.358	3.105	4.592	5.941	5.927	5.534
temperature (31℃-33℃)	2.688	0.419	2.789	0.566	2.004	1.036	0.738	1.057	1.217	1.226
temperature (34℃-36℃)	0.135	0.000	0.007	0.000	0.098	0.035	0.0 00	0.009	0.000	0.011
temperature (>=37℃)	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.004

Table 2 presents the descriptive statistics of the variables used in the regressions, including the relevant temperature and rainfall measures. As would be expected, the summer season, which is the wettest, receives average precipitation of 551 mm, while the average precipitation in the spring season is 334 mm.

Dependent variables: crop and farm level revenues[13]

The crop production system consists of cereals, pulses, legumes, oil seeds and other crops, with a given farm typically growing different crop types, each on a single plot. As will be discussed in the next section, the analysis is conducted at both the farm-level as well as plot level revenues. Accordingly, plot level characteristics are used for the plot level analysis while the (aggregated from plot level information are used as farm level characteristics in the analysis. For the plot level analysis two distinct categories are employed: small cereals, and large cereals & pulses. Small cereals include white, red and mixed teff, wheat, barley and oats. Large cereals include maize, sorghum, millets, rice, horse beans, cow peas, soya beans, lentils, chick peas, vetch, haricot bean and fava bean. The reason for such a grouping is because they have similar growing

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[13]We follow many Ricardian studies in developing countries for using agricultural profit instead of land values. The use of land values in such analyses requires perfection operation of land markets, so that land prices reflect the present discounted value of land rents into the infinite future (Deschenes and Greenstone, 2007). This condition does not hold in Ethiopia, as there is no information on prices for land sales due to full state ownership of the land (Di Falco et al., 2011).

temperature range and they also have similar soil quality and land preparation requirements. As per Table 2, the overall farm revenue averages at around Br. 3634 while that of small cereals and large cereals are Br. 340 and 260, respectively.

Socio-economic and physical farm characteristics

Around 18% of the surveyed households have a female head. The average age of the household head is 52.The proportion of household heads that are able to read and write is 56%. An average household has1.98 and 1.83 male and female adults of working age, respectively, indicating a gender balance between male and female labour availability. Livestock ownership, measured in tropical livestock units[14], is around 6 per household, while the number of oxen owned by an average household is around 2.

The average farm size is 1.60 ha, slightly higher than the national average of 1.1 ha. On average, 69% of the plots are flat, with moderately steep and steep plots making up the rest of the plots. In addition to topographic features, plots are defined by their soil colour, which is also a rough representation of other features such as water retention capacity and texture. An average of 40 percent of the plots per farm have black soil colour, while an average of 56% have red soil colour. The average proportion of fertile plots per household is 40%, while the average number of plots with moderately fertile and infertile soil types is 40% and 20%, respectively.

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[14] Tropical livestock unit is a common unit to describe livestock numbers of various species as a single figure that expresses the total amount of livestock present – irrespective of the specific composition (FAO, 2010). http://www.fao.org/ag/againfo/programmes/en/lead/toolbox/Mixed1-/TLU.htm

Table 2: Descriptive statistics of variables used in the regression

Variable name	Variable Description	Mean	S. Dev.	Mean	S. Dev.
Rainfall and Temperature* Variables		***Summer season***		***Spring season***	
average summer rainfall	the mean summer/spring rainfall corresponding to the survey year (mm)	551.40	226.31	390.46	216.91
temperature (<1℃)	the number of hours spent in th e <1℃ range in a given season	0.00	0.00	0.00	0.00
temperature (1℃-3℃)	the number of hours spent in the 1℃-3℃ range in a given season	25.04	10.04	2 3.69	5.97
temperature (4℃-6℃)	the number of hours spent in the <1℃ range in a given season	1.86	15.33	0.54	7.67
temperature (7℃-9℃)	the number of hours spent in the 7℃-9℃ range in a given season	17.48	58.10	1 1.30	29.63
temperature (10℃-12℃)	the number of hours spent in the 10℃-12℃ range in a given season	67.79	106 .93	60.89	65.97
temperature (13℃-15℃)	the number of hours spent in the 13℃-15℃ range in a given season	418.99	22 3.94	343.11	104.94
temperature (16℃-18℃)	the number of hours spent in the 16℃-18℃ range in a given season	463.19	83 .66	404.23	71.61
temperature (19℃-21℃)	the number of hours spent in the 19℃-21℃ range in a given season	423.70	14 2.83	255.21	52.46
temperature (22℃-24℃)	the number of hours spent in the 22℃-24℃ range in a given season	346.04	11 2.06	305.57	68.25
temperature (25℃-27℃)	the number of hours spent in the 25℃-27℃ range in a given season	230.14	21 3.73	376.42	89.62
temperature (28℃-30℃)	the number of hours spent in the 28℃-30℃ range in a given season	111.07	13 9.20	283.28	107.93
temperature (31℃-33℃)	the number of hours spent in the 31℃-33℃ range in a given season	22.74	41. 21	50.93	82.74
temperature (34℃-36℃)	the number of hours spent in the 34℃-36℃ range in a given season	0.26	1.41	1.27	4.95
temperature (>=37℃)	the number of hours spent in t he >=37℃ range in a given season	0.00	0.00	0.00	0 .00
long term temperature (<1℃)	the number of hours sp ent in the <1℃ range in a given season over a 30 year period	0.00	0.00	0.00	0.00
long term temperature (1℃-3℃)	the number of hours spent in the 1℃-3℃ range in a given season over a 30 year period	25.37	3.96	24.35	4.94
long term temperature (34℃-36℃)	the number of hours spent in the 34℃-36℃ range i n a given season over a 30 year period	0.25	0.53	2.34	1.93
long term temperature (>=37℃)	the number of hours spent in the >=37℃ range in a given season over a 30 year period	0.10	0.11	0.08	0.08
Physical farm characteristics					
temperature (31℃-33℃)	plot size	0.27	0.24		

temperature (34℃-36℃)	plot flat slope (1=yes ; 0 =otherwise)	0.70	0.46
temperature (>=37℃)	plot steep slope (1=yes ; 0=ot herwise)	0.04	0.19
soil slope:flat	plot medium slope (1=yes ; 0=otherwise)	0.26	0.44
soil quality of parcel:lem	plot highly fertile (1=yes ; 0=otherwise)	0.42	0.49
soil type (color) of parcel:black	plot black (1=yes ; 0=otherwise)	0.40	0.49
Socioeconomic characteristics			
number of oxen	The number of oxen	2.13	1.38
sex of household head	Sex of the household head	0.18	0.39
age of household head	Age of household head	52.27	16.40
household head literate	Head's formal education (1=read and write ; 0=otherwise)	0.56	0.50
number of male adults in household	The number of male working-age family member of the household	1.98	1.18
number of female adults in household	The number of female working-age family member of the household	1.83	1.01
Total land area by hh	Total farm size of the household in hectares	1.60	1.09
Dependent variables			
Crop revenue (small cereals)	Revenue from small cereal crops grown by the household	340.57	9176.33
Crop revenue (large cereals and pulses)	Revenue from large cereal and pulse crops grown by the household	260.48	289.34
Farm revenue	The sum of all revenues from the different crops grown by the household	3634.35	3006.27

Note: only the temperarture and rainfall values are presented by season.

Estimation Procedure

This section sets up a framework for analyzing the link between crop specific (or total farm) revenue on the one hand, and weather and climate variables on the other. We frame our analysis following the approach by Schlenker and Roberts (2006; 2009), which maps an entire season of temperature distribution to each year's yield, through the construction of temperature values, each depicting the number of hours/days spent in each three-degree range, over a growing season. This approach is extended to simultaneously incorporate both weather and climate measures as determinants of crop-specific and farm-level revenue, as presented in equation 1.

As Schlenker and Roberts (2006; 2009) argue, the essence of constructing such fine-scale weather data is to facilitate estimation of a flexible model that can detect nonlinearities and breakpoints in the effect of temperature on yield. Indeed, a potentially non-linear relationship between yield and temperature could be mis-specfied if the temperature measure is averaged over time or space, diluting the true temperature response in the process.

Accordingly, the estimated relationship between a crop revenue and temperature and rainfall is given by:

$$y_{iht} = \delta_{iht} + \beta x_{iht} + \sum_{j=1}^{n} \gamma_j r_{hjt} + \sum_{k=1}^{m} \mu_j S_{hk} + \vartheta w_{hit} + \varepsilon_{iht}$$
$$(1)$$

Where iht denotes the ith crop in farm household h in period t [15]. Revenue from the ith crop of farm household h at year t is denoted by y_{iht}. r_{hjt} represents the time spent in each degree range j over a growing season for each household h at year t, while S_{hk} represents the time spent in each of the extreme degree ranges k over a growing season for each household h over a 30 year period. The seasonal rainfall measures are represented by w_{hit} while x_{iht} are the socioeconomic and physical farm characteristic variables. The coefficients δ, β, γ, μ and ϑ represent the respective vector of parameter estimates, and ε_{ht} represents the error term. The composite error term $\varepsilon_{iht} = \alpha_{ih} + u_{iht}$ is composed of a normally distributed random error term, $u_{iht} \sim N(0, \sigma_u^2 u_{ij})$, and an unobserved household specific effect, α_{ih}. Rearranging

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[15] The same structure applies for farm level analysis, which is an aggregation of the crop-specific analysis at a farm level.

equation (1) by grouping time-variant and time invariant variables together, and introducing the fixed effect gives:

$$y_{iht} = \sigma z_{iht} + \varphi g_{ih} + \alpha_{ih} + u_{iht}$$
(2)

Under the assumption that α_{ih} is orthogonal to the observable covariates, a random effects estimator can be employed as an effective estimator (Baltagi 2001; Wooldridge 2002). However, allowing arbitrary correlation between α_{ih} and the regressors/observed covariates requires a fixed effect, as it takes α_{ih} to be a group-specific constant term and uses a transformation to remove this effect prior to estimation (Wooldridge 2002). The alternative approach of the random effects estimator has a specification similar to the fixed effects estimator, with the additional requirement of no correlation between the fixed effect α_{ih} and the regressors/observed covariates (Baltagi, 2001). Despite this shortcoming, however, the random effects estimator does not rely on the data transformation in the fixed effects estimator and thus is not affected by the associated shortcoming of removing any time-constant explanatory variables along with α_{ih} (Wooldridge, 2002). However, the random effects specification assumes exogeneity of all the regressors and the random individual effects. As long as the assumption of no correlation of the regressors and individual effects is satisfied, the random effects estimator guarantees a consistent and efficient estimator (Baltagi, 2001; Mundlak, 1978)[16].

To remedy the major drawback of removing the household specific effects of the fixed effects estimator, we employ the Mundlak-Krishnakumar fixed effects estimation approach. The approach involves explicitly modeling the relationship between time varying regressors and the unobservable effect in an auxiliary regression (Chatlain and Ralf, 2010).

In particular, α_{ih} can be approximated by its linear projection onto the observed explanatory variables:

$$\alpha_{ih} = \omega z_{ih} + \emptyset g_{ih} + v_{ih}$$
(3)

Where v_{iht} represents the random error term and Z_{ih} and g_{ih} are vector of all the average over time of time-varying and time invariant regressors in equation (3), respectively. Combining the auxiliary regression with the original equation (2) gives:

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[16]The standard test for this is the Hausman test with the null hypothesis that there is no significant difference between the coefficients of the fixed and random effects estimators (Wooldridge, 2002).

$$y_{iht} = \sigma z_{iht} + \varphi g_{ih} + \omega z_{ih} + \emptyset g_{ih} + \Omega_{iht}$$
(4)

Regrouping gives:

$$y_{iht} = (\sigma + \omega) z_{iht} + (\varphi + \emptyset) g_{ih} + \Omega_{iht}$$
(5)

Since the coeffienct φ could not be identified from $\emptyset$, in equation (5), estimating equation (5) would not yield consistent and unbiased estimates of the coefficients corresponding to the time invariant variables. Krishnakumar (2006) show that, in such instances, a procedure which undertakes a fixed effect estimation using only time variant covariates, followed by a regression of the time invariant covariates on the error term, enables recovering the coefficients of the time invariant covariates. However, Chatelain and Ralf (2010) argue that Mundlak's (1978) approach enables consistent estimation of the coefficients of both time-variant and time-invariant covariates if there is no correlation between the unobserved fixed effect and the time-invariant covariates.

In our case, we estimate both Mundlak-Krishnakumar and Mundlak's approaches with the alternative assumption that our time invariant variables are correlated and uncorrelated with the unobserved fixed effect.

Discussion of results

Table 3 presents the Mundlak-Krishnakumar estimation results of the determinants of revenue corresponding to crop/plot level analysis and aggregate farm level analysis. The first two columns focus on analysis of revenues corresponding to small cereals. Analysis of revenues corresponding to pulses and large cereals is presented in columns 3 and 4, while the aggregate farm level analysis is presented in columns 5 and 6. Each of the columns present the alternative results based on summer/spring temperature and rainfall values.

Analysis of the impact of the short term summer temperature on revenue from cereal crops shows statistically significant and positive impact of almost all the categories of short term temperature. The lower and upper extremes long term temperature value are negative and significant while the coefficient for one of the upper extremes is positive and significant. The results from analysis the determinants of small cereal revenues based on spring season temperature show that the impacts of short term spring temperature are generally significant and negative. Values corresponding to the upper extreme ends in the distribution of long term temperature values for the spring season are also negative and significant.

For pulses and large cereals, the effects of the different ranges of short term summer temperature measures are shown to be minimal. However, the extreme temperature values are found to have a significantly negative and large impact. Both ends of the long term spring temperature values are shown to have a consistently negative and significant impact, while the full range of short term spring temperature values are generally insignificant.

The results from the farm level analysis in columns 5 and 6 indicate that both short term summer and spring temperatures have a largely positive and significant impact on aggregate farm level revenue. Again, the extreme values of long term temperature, both in the summer and spring seasons, have strongly negative effect. It should be noted that these effects of extreme temperature are replicated for the different crop categories too. This shows that, in line with Schlenker and Roberts (2006; 2009), the results show that the extreme ends of the temperature distribution are always harmful for crop growth, irrespective of the type of crop[17].

Summer rainfall is found to have largely negative and significant effect on revenues from the different crop types as well as the aggregate farm revenue. While it is counter intuitive, these results could be an outcome of the correlation between temperature rainfall values (Burgess et al., 2013; Schlenker and Roberts, 2009). As we discuss below, the rainfall coefficients also change across estimation techniques indicating lack of robustness in the rainfall results.

Of the soil characteristics, large plot size, fertile plots, flat-slopped plots have generally positive impact on productivity, while soil color has inconsistent and largely insignificant impact. These results are in line with expectations that desirable physical farm characteristics are positive contributors to agricultural revenue. Number of oxen has a positive and significant impact on small cereal revenue, indicating the importance of the lack of oxen ownership as a major constraint to productivity. Education has a reasonably significant impact on agricultural revenues of cereal crops. The effect of the number of male adults and female adults is positive and significant, with the female adult labor availability having a smaller impact in terms of magnitude. This indicates that male labor availability is a binding constraint to agricultural productivity, at least for small cereals. Land size has negative and significant impact on crop revenues, conforming to the inverse farm size-productivity relationships found in other studies.

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[17] Burgess et al. (2013) also find similar patterns of temperature on Mortality in India.

Table 3: Mundlak-Krishnakumar Fixed Effects Estimation of the Impacts of Climate Change and Weather on crop/farm level revenue

	Small cereals		Pulses and large cereals		All crops/farm level	
	Summer	Spring	Summer	Spring	Summer	Spring
temperature (1℃-3℃)	-0.979	13.212***	0.79	5.056	4.918	18.854***
	(1.290)	(3.495)	(1.316)	(3.320)	(5.428)	(5.334)
temperature (4℃-6℃)	4.320**	-10.708***	0.838	-4. 327*	17.049**	-10.177***
	(1.781)	(2.435)	(2.145)	(2.389)	(7.292)	(3.709)
temperature (7℃-9℃)	4.011*	1.19	1.117	-0.215	20.304**	5.312***
	(2.198)	(0.933)	(2.561)	(1.142)	(9.155)	(1.374)
temperature (10℃-12℃)	3.625*	-2.146**	1.205	-1.5 77	19.050**	2.527*
	(2.181)	(1.041)	(2.537)	(1.230)	(9.071)	(1.531)
temperature (13℃-15℃)	4.537**	-1.906*	1.167	-0.7 91	21.517**	3.273**
	(2.193)	(1.010)	(2.542)	(1.209)	(9.125)	(1.482)
temperature (16℃-18℃)	3.579	-0.862	0.129	-0.103	18.512**	3.916**
	(2.236)	(1.065)	(2.573)	(1.253)	(9.284)	(1.554)
temperature (19℃-21℃)	2.766	-1.386	1.39	-1.189	16.976*	3.043**
	(2.143)	(0.945)	(2.529)	(1.147)	(8.937)	(1.416)
temperature (22℃-24℃)	3.653*	-2.006**	1.12	-0.97	18.452**	2.924**
	(2.176)	(0.990)	(2.539)	(1.180)	(9.057)	(1.450)
temperature (25℃-27℃)	3.821*	-2.363**	1.571	-1.8 33	19.087**	2.525*
	(2.160)	(0.993)	(2.530)	(1.194)	(9.003)	(1.478)
temperature (28℃-30℃)	2.797	-2.009**	0.756	-1.22 9	16.575*	2.669*
	(2.172)	(0.977)	(2.535)	(1.181)	(9.043)	(1.441)
temperature (31℃-33℃)	6.224***	-1.634	0.705	-1.1 55	25.089***	3.446**

	(1)	(2)	(3)	(4)	(5)	(6)
	(2.240)	(1.032)	(2.577)	(1.227)	(9.297)	(1.515)
temperature (34℃-36℃)	2.856	.	6.824*	.	-0.921	.
	(3.304)	.	(3.542)	.	(13.194)	.
long term temperature (1℃-3℃)	-4.567***	-4.086***	-0.452	-2.386***	-18.462***	-0.905***
	(0.331)	(0.299)	(0.440)	(0.330)	(2.320)	(0.186)
long term temperature (34℃-36℃)	16.325***	27.168* **	0.75	26.465***	21.210*	4.361***
	(1.945)	(1.054)	(2.062)	(1.143)	(11.602)	(0.585)
long term temperature (>=37℃)	-126.942***	-465.606***	-80.851***	-608.903***	-123.299*	-98.030***
	(9.951)	(26.587)	(11.400)	(27.342)	(63.613)	(14.169)
Summer/spring rainfall	0.016	-0.062**	-0.119***	-0.067**	-0.216**	-0.108***
	(0.222)	(0.028)	(0.023)	(0.028)	(0.090)	(0.036)
Plot size in hectars: calculated	394.554***	429.420***	337.017***	346.734***	72.704	333.583***
	(14.312)	(14.542)	(13.172)	(13.464)	(72.398)	(26.691)
slope of parcel:meda	-5.222	-10.233	-2.678	-5.395	71.984*	12.975
	(7.387)	(7.507)	(7.120)	(7.257)	(41.797)	(15.216)
soil quality of parcel:lem	36.882***	14.151**	-6.206	-11.765*	70.617**	-6.32
	7.104	7.201	6.553	6.667	35.689	13.34
soil type (color) of parcel:black	13.662*	-11.502	-25.069***	-38.937***	-135.528***	-75.004***
	(7.144)	(7.202)	(6.600)	(6.693)	(39.774)	(14.388)
Constant	150.615***	97.912***	18.364	47.078***	490.252***	26.741***
	(9.006)	(8.291)	(11.716)	(9.087)	(62.886)	(5.025)
N	9810	9810	6293	6293	4844	4799
Year Dummy	YES	YES	YES	YES	YES	YES
Wald Chi2	1904.82	1481.79	1306.88	935.29	1288.30	384.01
Prob>chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Socioeconomic characteristics	YES	YES	YES	YES	YES	YES

* P<0.1, **p<0.05, ***p<0.001

Note: 1) The farm level analysis in the last two columns aggregates the revenues from all crops/plots at a farm level. Hence, the analysis is at a farm household level, instead of at a plot level, unlike the first four columns.

2) The socioeconomic characteristics controlled for include total land area, illiteracy, age of the household head, gender of the household head, number of oxen and   livestock, number of male adult members, number of female adult members.

Tables 4 presents the Mundlak's pseudo fixed effects estimation results corresponding to the determinants of revenues from small cereal crops. In the first panel of Table 4, the results based on summer temperature measures are presented. In the second panel, the results from the spring temperature measures are presented. In each of the panels, the first column presents the regression results based on short term temperature measures. The succeeding columns gradually add long term temperature measures, rainfall measures, physical farm characteristics, and finally socioeconomic characteristics. While the results reported in the earlier columns are added as robustness checks, discussion of the results is based on the last column in each panel where all these variables are controlled for.

The results corresponding to short term temperature are positive and significant while the results for short term spring temperature are negative and signficant. Similarly, for long term temperature measures, both the lower (<3 degree Celsius) and upper (>37 degree Celsius) coefficients show strongly significant and negative impacts on the small cereal revenue. In comparison with the impacts of both short and term temperature based on the Mundlak-Krishnakumar estimator (Table 3), this indicates that that temperature has consistent impact on revenue from small cereals. Spring rainfall (short term) has a positive and significant impact, while summer rainfall is insignificant. The impacts of the physical farm and socioeconomic characteristics are similar to the results in the Mundlak-Krishnakumar analysis. In addition, these results are also shown to generally hold when using (dropping) other controls, such as physical farm characteristics, socioeconomic characteristics and rainfall, indicating the robustness the temperature results-the main focus of our analysis.

Table 4: Pseudo-Fixed Effects Estimation of the Impacts of Climate Change and Weather on crop level revenue (small cereals)**

	Analysis based on summer temperature					Analysis based on spring temperature				
	teff1	teff2	teff3	teff4	teff5	teff1	teff2	teff3	teff4	teff5
temperature (1℃-3℃)	0.478	0.451	2.606**	1.987*	2 .816**	9.911***	9.482***	9.324***	10.243***	6.821**
	(0.920)	(0.972)	(1.241)	(1.189)	(1.170)	(3.474)	(3.543)	(3.537)	(3.381)	(3.282)
temperature (4℃-6℃)	-0.125	0.436	5.374***	3.843* *	3.623**	-7.410***	-7.837***	.	.	-4.905**
	(0.556)	(0.589)	(1.852)	(1.799)	(1.757)	(2.287)	(2.302)	.	.	(2.308)
temperature (7℃-9℃)	0.307***	0.293***	6.449***	4 .669**	4.814**	2.230***	0.785***	8.356***	9.307***	2.497***
	(0.085)	(0.086)	(2.197)	(2.126)	(2.083)	(0.196)	(0.280)	(2.303)	(2.202)	(0.941)
temperature (10℃-12℃)	-0.138**	0.023	6.121***	4. 289**	4.526**	-2.407***	-1.413***	6.189***	6.766***	-0.31
	(0.065)	(0.073)	(2.178)	(2.108)	(2.064)	(0.135)	(0.193)	(2.288)	(2.187)	(1.089)
temperature (13℃-15℃)	0.386***	0.453***	6.603***	4.625**	4.856**	1.131***	1.108***	8.697***	9.039***	2.101*
	(0.067)	(0.074)	(2.191)	(2.120)	(2.077)	(0.107)	(0.109)	(2.244)	(2.145)	(1.051)
temperature (16℃-18℃)	0.359**	0.364**	6.649***	4 .437**	4.676**	-1.592***	-0.934***	6.728***	7.770***	0.839
	(0.145)	(0.152)	(2.245)	(2.173)	(2.129)	(0.287)	(0.301)	(2.210)	(2.113)	(1.126)
temperature (19℃-21℃)	-0.591***	-0.345***	5.616***	3.846*	4.110**	5.055***	4.014***	11.368***	10.862***	4.191**
	(0.101)	(0.105)	(2.136)	(2.069)	(2.026)	(0.283)	(0.322)	(2.309)	(2.207)	(0.974)
temperature (22℃-24℃)	0.049	0.073	6.157***	4.366 **	4.706**	-3.448***	-3.567***	4.007*	4.778**	-1.970*
	(0.066)	(0.066)	(2.169)	(2.100)	(2.057)	(0.252)	(0.258)	(2.289)	(2.188)	(1.018)
temperature (25℃-27℃)	-0.253***	0.204**	6.218***	4.377**	4.519**	0.18	0.299*	7.848***	7.916***	0.988
	(0.074)	(0.097)	(2.149)	(2.081)	(2.037)	(0.147)	(0.153)	(2.304)	(2.202)	(1.047)
temperature (28℃-30℃)	-0.884***	-0.383**	5.638***	3.797*	4.225**	-0.244**	-0.387***	7.136***	7.448***	0.621

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	(0.124)	(0.155)	(2.155)	(2.086)	(2.043)	(0.097)	(0.106)	(2.276)	(2.175)	(1.005)
temperature (31℃-33℃)	1.686***	1.410***	7.514***	5.909***	5.975***	-1.689***	-1.527***	6.095***	6.770***	-0.082
	(0.271)	(0.333)	(2.198)	(2.125)	(2.084)	(0.103)	(0.105)	(2.262)	(2.162)	(1.067)
temperature (34℃-36℃)	-9.151***	-13.106***	-8.257**	-0.864	-4.013	-0.208	-2.100*	5.111**	8.457***	.
	(2.625)	(2.924)	(3.389)	(3.278)	(3.197)	(0.928)	(1.090)	(2.472)	(2.368)	.
long term temperature (1℃-3℃)		-8.383***	-8.489***	-7.987***	-8.877***		-2.249	-1.653	-2.579	-2.75
		(1.792)	(1.792)	(1.754)	(1.723)		(1.820)	(1.831)	(1.802)	(1.748)
long term temperature (34℃-36℃)		53.039**	67.474***	24.692	22.615		24.074**	20.357***	19.356***	23.536***
		(17.639)	(18.314)	(17.709)	(17.231)		(4.893)	(4.996)	(4.797)	(4.755)
long term temperature (>=37℃)		-1033.7**	-948.0***	-797.289***	-840.298***		-90.588	-22.825	-30.778	-62.579
		(181.076)	(184.653)	(178.110)	(175.964)		(117.285)	(118.468)	(113.578)	(111.377)
summer/spring rainfall			-0.028	-0.008	-0.003			0.075***	0.074***	0.047*
			(0.021)	(0.020)	(0.020)			(0.026)	(0.025)	(0.025)
Plot size in hectars: calculated				440.278***	462.031***				453.864**	467.608**
				(13.873)	(15.036)				(13.952)	(15.105)
slope of parcel:meda				5.876	7.077				0.777	2.589
				(7.051)	(6.958)				(7.070)	(6.985)
soil quality of parcel:lem				24.370***	30.826***				18.796***	24.147***
				(6.906)	(6.847)				(6.922)	(6.867)
soil type (color) of parcel:black				-3.039	-2.346				-6.541	-6.103
				(6.920)	(6.856)				(6.943)	(6.885)
Constant	346.334*	352.797***	-12700***	-8746.3*	-9339.2**	407.2***	400.6***	-1.5800*	-1.6700**	-2056.704
	(23.726)	(23.768)	(4674.814)	(4525.155)	(4432.659)	-(23.725)	-(23.846)	(4908.3)	(4691.1)	(2205.6)
N	10620	10620	10405	10258	9812	10620	10620	10405	10258	9812

Year Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Mundlak's fixed effects	NO	NO	NO	NO	YES	NO	NO	NO	NO	YES
Adjusted R-sq	0.1446	0.15	0.153	0.2342	0.2642	0.135	0.1394	0.1425	0.2281	0.2568
Socioeconomic characteristics	NO	NO	NO	NO	YES	NO	NO	NO	NO	YES

*$P<0.1$, **$p<0.05$, ***$p<0.001$*

Note: 1) The farm level analysis in the last two columns aggregates the revenues from all crops/plots at a farm level. Hence, the analysis is at a farm household level, instead of at a plot level, unlike the first four columns.

2) The socioeconomic characteristics controlled for include total land area, illiteracy, age of the household head, gender of the household head, number of oxen and   livestock, number of male adult members, number of female adult members.

Table 5 presents Mundlak's pseudo fixed effects estimation results for pulses and large cereals. Short term summer temperature is shown to have a generally insignificant on the revenue from this category of crops, but short term spring temperature has a positive and significant effect. The extreme ends of the long term temperature value are consistently negative for both spring and summer measures. The major (summer) season rainfall and minor (spring season rainfall are also largely insignificant. The impact of physical farm characteristics is largely insignificant, except plots with black soil colour showing negative impact on revenues from pulses and large cereals. Comparing Tables 4 and 5 shows that the patterns of the impact of socioeconomic characteristics is largely identical across the two crop categories, the impact of adult female labour is not significant in the large cereal and pulses category. This could be due to the fact that the small cereals are susceptible to weeds, a largely female labour task, making the availability of female labour more critical in the case of small cereal crops.

Table 5: Pseudo-Fixed Effects Estimation of the Impacts of Climate Change and Weather on crop level revenue (large cereals and pulses)**

	Analysis based on summer temperature					Analysis based on spring temperature				
	pulses1	pulses2	pulses3	pulses4	pulses5	pulses1	pulses2	pulses3	pulses4	pulses5
temperature (1℃-3℃)	-2.222**	-0.433	0.908	-0.103	0.673	16.95***	13.123***	13.148***	12.352***	6.625**
	(1.009)	(1.054)	(1.296)	(1.231)	(1.185)	(3.291)	(3.401)	(3.404)	(3.221)	(3.184)
temperature (4℃-6℃)	1.390**	0.313	4.888**	1.242	3.205	-10.98***	-9.556***	.	-9.366***	.
	(0.605)	(0.638)	(2.426)	(2.407)	(2.364)	(2.147)	(2.170)	.	(2.366)	.
temperature (7℃-9℃)	0.328***	0.135	5.440**	1.298	3.481	0.017	-0.577*	8.979***	-0.614	4.615**
	(0.099)	(0.101)	(2.767)	(2.727)	(2.671)	(0.202)	(0.323)	(2.186)	(1.231)	(2.054)
temperature (10℃-12℃)	0.083	0.027	5.229*	1.024	3 .304	-0.946***	-0.091	9.552***	-0.33	5.579***
	(0.062)	(0.074)	(2.725)	(2.686)	(2.629)	(0.131)	(0.220)	(2.169)	(1.407)	(2.031)
temperature (13℃-15℃)	0.324***	0.161*	5.422**	1. 085	3.278	0.815***	0.645***	10.227***	0.223	6.034***
	(0.077)	(0.085)	(2.738)	(2.697)	(2.640)	(0.113)	(0.118)	(2.124)	(1.356)	(1.988)
temperature (16℃-18℃)	-0.534***	-0.877***	4.477	0.321	2.448	1.237***	1.214***	10.877***	1.003	7.246***
	(0.179)	(0.186)	(2.796)	(2.749)	(2.694)	(0.313)	(0.343)	(2.078)	(1.443)	(1.933)
temperature (19℃-21℃)	0.368***	0.676***	5.788**	1.547	3.889	0.03	-0.342	9.176***	-0.987	4.474**
	(0.123)	(0.131)	(2.710)	(2.676)	(2.618)	(0.304)	(0.381)	(2.208)	(1.253)	(2.078)
temperature (22℃-24℃)	-0.279***	-0.284***	4.908*	0.769	3.112	-1.534***	-1.068***	8.547***	-1.338	4.470**
	(0.075)	(0.075)	(2.719)	(2.681)	(2.624)	(0.233)	(0.263)	(2.148)	(1.311)	(2.013)
temperature (25℃-27℃)	0.841***	1.236***	6.414**	1.986	4.127	-0.891***	-0.559***	9.043***	-0.91	4.707**
	(0.088)	(0.103)	(2.716)	(2.681)	(2.621)	(0.150)	(0.169)	(2.198)	(1.370)	(2.064)
temperature (28℃-30℃)	-1.072***	-0.208	4.870*	0. 719	2.864	-1.103***	-0.852***	8.723***	-1.145	4.525**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	(0.132)	(0.166)	(2.696)	(2.656)	(2.594)	(0.108)	(0.122)	(2.152)	(1.318)	(2.018)
temperature (31℃-33℃)	1.169***	0.867**	6.214**	1 .933	3.731	-0.533***	-0.279**	9.340***	-0.591	5.259***
	(0.291)	(0.350)	(2.764)	(2.722)	(2.657)	(0.117)	(0.126)	(2.141)	(1.383)	(2.003)
temperature (34℃-36℃)	0.573	2.911	6.719*	8.000**	6.772*	-1.766	-1.059	8.404***	.	3.878*
	(3.000)	(3.324)	(3.824)	(3.695)	(3.555)	(1.196)	(1.410)	(2.496)	.	(2.351)
long term temperature (1℃-3℃)		2.02	1.71	1.125	-0.928		-6.870**	-6.831**	-4.706	-6.612**
		(2.129)	(2.130)	(2.055)	(2.041)		(3.019)	(3.043)	(3.051)	(2.977)
long term temperature (34℃-36℃)		-34.270**	-23.254	-47.384***	-17.501		37.547***	38.150***	33.362***	42.314***
		(14.399)	(15.478)	(14.905)	(15.959)		(5.475)	(5.654)	(5.368)	(5.317)
long term temperature (>=37℃)		-1469.4***	-1372.4* **	-1163.1***	-820.9***		-702.1***	-703.1***	-600. 7***	-619.4***
		(174.656)	(179.025)	(172.000)	(175.235)		(122.400)	(123.846)	(117.625)	(114.531)
summer/spring rainfall			-0.056**	-0.036	-0.036			0.001	0.023	0.006
			(0.023)	(0.022)	(0.022)			(0.027)	(0.026)	(0.026)
Plot size in hectars: calculated				365.338***	398.979***				384.644***	419.401***
				(13.099)	(14.298)				(13.182)	(14.424)
slope of parcel:meda				4.177	4.838				-0.523	1.419
				(6.932)	(6.990)				(6.996)	(7.058)
soil quality of parcel:lem				-4.981	-2.376				-2.168	0.337
				(6.497)	(6.554)				(6.566)	(6.639)
soil type (color) of parcel:black				-33.480***	-32.367***				-34.691***	-34.419***
				(6.517)	(6.625)				(6.612)	(6.734)
Constant	103.546***	150.813***	-1.10e+04*	-1981.778	-6797.614	246.6***	220.234***	-20340**	868.848	-11400***
	(30.151)	(30.570)	(5863.083)	(5778.259)	(5655.47)	(31.277)	(31.675)	(4637.46)	(2873.39)	(4341.56)
Year Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Mundlak's fixed effects	NO	NO	NO	NO	YES	NO	NO	NO	NO	YES

2

Chi-squared	0.1183	0.1276	0.1306	0.2172	0.2667	0.1353	0.1498	0.1536	0.2244	0.2252
N	7247	7247	7153	7093	6294	7247	7247	7153	7093	6294
Socioeconomic characteristics		NO	NO	NO	NO	YES	NO	NO	NO	NO	YES

* P<0.1, **p<0.05, ***p<0.001

Note: 1) The farm level analysis in the last two columns aggregates the revenues from all crops/plots at a farm level. Hence, the analysis is at a farm household level, instead of at a plot level, unlike the first four columns.

2) The socioeconomic characteristics controlled for include total land area, illiteracy, age of the household head, gender of the household head, number of oxen and livestock, number of male adult members, number of female adult members.

For farm level revenue, comparison of the results from Table 6 (Mundlak's pseudo fixed effects estimator) and Table 3 (Mundlak-Krishnakumar estimator) show that both short term summer and spring temperatures have generally positive and significant effects. Summer and spring precipitation has no significant effect, based on the results from Table 6. Flat-slopped plots, having one of the desirable physical farm characteristics are associated with plots with significantly higher revenue. The effects of the physical farm characteristics and socioeconomic characteristics remain similar to those of the crop-specific analyses.

Table 6: Pseudo-Fixed Effects Estimation of the Impacts of Climate Change and Weather on farm level revenue (all crops)**

	Analysis based on summer temperature					Analysis based on spring temperature				
	allcrops1	allcrops2	allcrops3	allcrops4	allcrops5	allcrops1	allcrops2	allcrops3	allcrops4	allcrops5
temperature (1℃-3℃)	2.354	3.994	9.631	9.267	12.0 49**	101.6***	99.8***	81.482***	79.791***	51.406***
	(3.903)	(4.107)	(5.991)	(5.950)	(5.433)	(15.094)	(15.721)	(16.321)	(16.194)	(14.926)
temperature (4℃-6℃)	1.072	-0.961	-3.281	-3.94	8. 982	-68.1***	-69.9***	-47.818***	.	-27.750***
	(2.531)	(2.660)	(8.697)	(8.651)	(7.972)	(9.818)	(10.087)	(11.179)	.	(10.272)
temperature (7℃-9℃)	1.823***	1.710***	0.509	-0.1 07	14.182	8.107***	5.615***	13.810***	60.841***	14.293***
	(0.374)	(0.376)	(10.391)	(10.338)	(9.527)	(0.854)	(1.095)	(4.563)	(10.436)	(4.103)
temperature (10℃-12℃)	0.111	-0.225	-0.241	-1.095	12.234	-7.5***	-5.9***	10.688**	57.132***	7.386
	(0.255)	(0.292)	(10.272)	(10.219)	(9.408)	(0.495)	(0.699)	(5.438)	(10.353)	(4.909)
temperature (13℃-15℃)	0.890***	0.630**	0.624	-0. 431	13.244	3.505***	3.069***	16.393***	62.434***	14.020***
	(0.272)	(0.290)	(10.339)	(10.287)	(9.474)	(0.432)	(0.451)	(5.161)	(10.164)	(4.669)
temperature (16℃-18℃)	-0.441	-1.025	-1.293	-2.16 2	11.896	-3.9***	-3.8***	12.580**	59.109***	12.218**
	(0.614)	(0.642)	(10.584)	(10.532)	(9.716)	(0.931)	(0.932)	(5.588)	(9.918)	(5.073)
temperature (19℃-21℃)	-0.820**	-0.792*	-0.012	-0 .858	11.679	14.1***	12.17***	24.391***	69.691***	18.487***
	(0.408)	(0.420)	(10.115)	(10.064)	(9.256)	(1.017)	(1.111)	(4.664)	(10.525)	(4.229)
temperature (22℃-24℃)	0.259	0.18	-0.899	-1.514	1 2.269	-13.5***	-13.5***	2.129	48.809***	-0.084
	(0.271)	(0.274)	(10.236)	(10.185)	(9.375)	(0.991)	(1.024)	(4.980)	(10.278)	(4.493)
temperature (25℃-27℃)	0.154	0.43	0.907	-0.187	12 .772	-0.193	0.588	14.590***	60.535***	9.901**
	(0.304)	(0.381)	(10.176)	(10.126)	(9.313)	(0.538)	(0.572)	(5.171)	(10.489)	(4.668)
temperature (28℃-30℃)	-2.6***	-1.983***	0.004	-0 .703	11.45	-2.9***	-2.9***	9.998**	56.348***	7.539*
	(0.511)	(0.606)	(10.186)	(10.138)	(9.314)	(0.355)	(0.384)	(4.949)	(10.296)	(4.460)
temperature (31℃-33℃)	3.701***	3.203**	3.124	2.3 85	16.159*	-5.78***	-5.45***	8.081	54.693***	6.94
	(1.131)	(1.329)	(10.400)	(10.345)	(9.513)	(0.415)	(0.432)	(5.272)	(10.222)	(4.758)

temperature (34℃-36℃)	-5.982	-0.913	-9.811	-2.80 1	4.564	-5.611	-10.24**	.	48.919***	.
	(11.369)	(12.601)	(15.559)	(15.467)	(14.003)	(3.785)	(4.302)	.	(11.101)	.
long term temperature (1℃-3℃)		16.669**	-17.587**	-19.175**	-32.762***		7.591	-22.490**	-23.111**	-18.244**
		(7.502)	(8.750)	(8.724)	(8.018)		(7.364)	(9.399)	(9.325)	(8.441)
long term temperature (34℃-36℃)		-48.947	-149.414**	-174.434***	-52.486		55.255***	167.631***	156.542***	112.507**
		(60.493)	(67.908)	(67.647)	(66.428)		(18.887)	(23.373)	(23.258)	(21.480)
long term temperature (>=37℃)		-1369.7**	-4954.5**	-4676.4***	-2738.5***		-371.973	-1462.9***	-1157.8**	-689.171
		(687.217)	(766.443)	(766.020)	(728.414)		(460.238)	(526.073)	(523.629)	(477.088)
Annual rainfall			-0.148	-0.107	-0.056			0.239**	0.245**	0.168
			(0.094)	(0.093)	(0.086)			(0.115)	(0.114)	(0.109)
Plot size in hectars				501.571***	-662.7***				555.2***	-564.78***
				(74.819)	(83.222)				(74.262)	(82.757)
soil slope:flat				118.692***	94.406**				90.668**	80.843**
				(42.174)	(39.735)				(42.103)	(39.736)
soil quality of parcel:lem				-5.134	45.071				5.052	48.383
				(38.060)	(36.400)				(38.100)	(36.477)
soil type (color) of parcel:black				-252.2***	-179.46***				-256.4***	-195.41***
				(40.790)	(39.341)				(40.842)	(39.545)
Constant	919.01***	1171.360***	-2.88E+04	-3676.047	-2.84E+04	1819.589***	1653.717***	-1.25e+05***	-1.58e+05***	-1.21e+05***
	(278.416)	(277.313)	(55324.632)	(55024.216)	(49162.744)	(280.590)	(279.841)	(27774.790)	(56562.157)	(24365.361)
Year Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Mundlak's fixed effects	NO	NO	NO	NO	YES	NO	NO	NO	NO	YES
Adjusted R-sq	0.2044	0.2173	0.2706	0.2855	0.4997	0.1777	0.1964	0.2379	0.2568	0.4727
N	7107	7107	5569	5551	4845	7107	7107	5569	5551	4845
Socioeconomic characteristics		NO	NO	NO	NO	YES	NO	NO	NO	NO	YES

*P<0.1, **p<0.05, ***p<0.001*

Note: 1) The farm level analysis in the last two columns aggregates the revenues from all crops/plots at a farm level. Hence, the analysis is at a farm household level, instead of at a plot level, unlike the first four columns.

2) The socioeconomic characteristics controlled for include total land area, illiteracy, age of the household head, gender of the household head, number of oxen and   livestock, number of male adult members, number of female adult members.

Conclusions

A large body of literature demonstrates negative impacts of climate change on the agricultural sector. In particular, as climate change is likely to intensify the effects of high temperatures and low precipitations, its most dramatic impacts will be felt by smallholder and subsistence farmers suffering the brunt of the effects (Mendelsohn et al., 2004). In this study, we examine the possible impacts of climate change based on data from Ethiopia, a rain-fed agrarian economy with notorious fluctuations in weather and frequent drought. This paper emphasizes the importance of simultaneously considering the impacts of weather and climate in such settings, as the focusing on either measure may leave out the distinct effects of each of the measures.

Accordingly, we assessed the importance of weather and climate variables on agricultural revenues using plot level panel data from the Amhara Region of Ethiopia. This is combined with 30-year meteorological data corresponding to survey villages, interpolated at an individual farm level. The analysis employs 14 temperature categories related to short term (weather) measures and four categories corresponding with the extreme ends of the long term temperature distribution (climate measures). The analysis distinguishes between summer and spring seasons and different crops in recognition of Ethiopia's is a multi-cropping and multi-season agriculture.

The major findings of the analysis could be summarized in three ways. First, temperature effects are distinctly non-linear, with extreme temperature values having consistently negative effects across seasons and crop types. In this respect, our finding is similar to previous studies that registered significant the non-linear impacts of temperature, using weather variables. However, The fact that non-linearity is consistently detected in the extreme ends of the distribution of long term temperature values points to the importance of simultaneously analysing the impacts of weather and climate measures to detect such distinctions. Second, the impact of temperature drastically varies across crops and across seasons for a single crop. This result highlights the potentially heterogeneous impacts of climate change even within a farm and a given year, indicating the need for understanding such complexities in the design of crop insurance and climate change policies. Third, rainfall generally has less important role to play than temperature, evidenced by inconsistent signs and significance across estimators, contrary to expectations in rain-fed agriculture.

In sum, given the general tendency of previous related studies to focus on either long term or short term measures of temperature and rainfall, this study takes an important stride in incorporating short term and long term temperature patterns simultaneously. Indeed, our analysis shows significant responsiveness of agricultural productivity to both weather variability and climate change. Given the multi-cropping nature of our farming system, however, a number of crop types are lumped into one category. This implies that the likelihood of a wide spectrum of weather effects being represented in our analysis could be low. Future studies that look into the simultaneous impacts of weather and climate change on individual crops would more accurately illuminate our

understanding of the underlying relationships. We may note, however, that to the extent that the pattern of climate change mimics weather uncertainty, policy measures aimed at mitigating the impacts of climate change could also serve the same purpose as those for weather uncertainty. From policy perspective, the results highlight the need to factor in the distinction between crops and seasons in designing yield insurance measures. In addition, insurance schemes also need to look into specific measures that target extreme values.

References

Adams RM, Flemming RA, Chang CC, McCarl B, Rosenzweig C (1995) A reassessment of the economic effects of global climate change on U.S. agriculture. Climatic Change 30:147–167.

Adenew, B. 2006. Effective Aid for Small Farmers in Sub-Saharan Africa: Southern Civil Society Perspectives—Ethiopia Case Study. Addis Ababa, Ethiopia: Canadian Food Security Policy Group. http://www.ccic.ca/_files/en/working_groups/003_food_2007-01_small_farmers_research_report_ethiopia.pdf. Accessed 23 February 2010.

AfDB (African Development Bank) (2011). Federal Democratic Republic of Ethiopia: Country Strategy Paper 2011-15, April.

Auffhammer, M., S. Hsiang, W. Schlenker, A. Sobel (2013) Using weather data and climate model output in economic analyses of climate change. Rev. Environ. Econ. Policy 7, 181–198

Barrett, C.B., ,B.J. Barnett, M.R. Carter, S. Chantarat;, J.W. Hansen;, A.G. Mude , D.E. Osgood, J.R. Skees, C.G. Turvey, M.N. Ward, 2007. Poverty Traps and Climate Risk: Limitations and Opportunities of Index-Based Risk Financing, IRI Technical Report 07-03 Working Paper, Columbia University.

Batagi, B.H. (2001). Econometric Analysis of Panel Data (Second Edition), New York, Wiley.

Black JR, Thompson SR (1978) Some evidence on weather-crop-yield interaction. American Journal of Agricultural Econ 60:540–543.

Brown RA, Rosenberg NJ (1999) Climate change impacts on the potential productivity of corn and winter wheat in their primary United States growing regions. Climatic Change 41:73–107.

Burgess, R., O. Deschenes, D. Donaldson, M. Greenestone (2013) The Unequal Effects of Weather and Climate Change: Evidence from Mortality in India.

Cao, J. 2008. Reconciling Human Development and Climate Protection: Perspectives from Developing Countries on Post-2012, International Climate Change Policy. Discussion Paper 08-25. The Harvard Project on International Climate Agreements, Kennedy School of Government, Harvard University.

Chatelain, J and K. Ralf (2010) Inference on Time invariant variables using Panel Data: A pre-Test Estimator with an Application to the Returns to Schooling. *PSE Working Paper*. Available at http://hal-paris1.archives-ouvertes.fr/docs/00/49/20/39/PDF/Chatelain_Ralf_Time_Invariant_Panel.pdf

Cassman, Kenneth G. (1999) Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. Proceedings of the National Academy of Science of the United States of America, 96(11):5952-5959, 1999.

Dai, A., K. E. Trenberth, and T. Qian (2004). A global data set of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. J. Hydrometeorology, 5:1117-1130, 2004.

Dercon, S., 2009 Risk, poverty and insurance, IFPRI Focus 17(3), International Food Policy Research Institute (IFPRI), Washington DC.

Devereux, S. 2000. Food Insecurity in Ethiopia: A Discussion Paper for DFID. Sussex, UK: IDS. http://cramforum.jrc.it/Shared%20Documents/Food%20Insecurity%20in%20-Ethiopia.pdf. Accessed 23 February 2010.

De Salvo, M., R. Roberta and M. Riccarda (2013). The impact of climate change on permanent crops in an Alpine region: A Ricardian analysis. Agricultural Systems 118: 23-32.

Deschênes, Olivier, and Michael Greenstone (2007). The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather. American Economic Review, 97(1): 354–385.

Salvatore Di Falco and Marcella Veronesi (2013). How African Agriculture Can Adapt to Climate Change? Countefactual Analysis from Ethiopia. Land Economics. 89 (4): 743-766.

Di Falco, Salvatore, Marcella Veronesi and Mahmud Yesuf (2011) Does Adaptation To Climate Change Provide Food Security? A Micro-Perspective from Ethiopia, American Journal of Agricultural Economics, 93(3): 829-846.

Fezzi, Carlo. I. Bateman, and W. Schlenker (2010) The Ricardian Approach with Panel Data and Flexible Functional Forms: An Additive Mixed Model applied to England and Wales farmland.
values.http://www.webmeets.com/files/papers/WCERE/2010/1528/paper%20CC-%20%20_%20conference%20version.pdf

Fisher, A., W. M. Hanemann, M.J. Roberts, and W. Schlenker (2012) The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather: Comment. American Economic Review. 102:3749-3760.

Gutro, Rob (2005). NASA's Earth-Sun Science News Team/SSAINASA Goddard Space Flight Center, Greenbelt, Md., and excerpts from NOAA's CPC web page, and the U.S. EPA web page. 2/2005Edits: Dr. J. Marshall Shepherd, NASA/GSFC, Drew Shindell, NASA/GISS, Cynthia M. O'Carroll, NASA/GSFC.

Grierson, W. (2002) Role of Temperature in the Physiology of Crop Plants: Pre- and Post-Harvest, in Mohammed Pessarakli (editor), Handbook of Plant and Crop Physiology, New York: MarcelDekker.

Hodges, T, ed. (1991): Predicting Crop Phenology, Boca Raton: CRC Press, 1991.

Krishnakumar, Jaya (2006) Time invriant variables and panel data models: a generalised Frisch-Waugh theorem and its implications. Chap. 5 In 'Panel data econometrics: theoretical

contributions and empirical applications', edited by Badi H. Baltagi. 119-32. Amsterdam: Elsevier.
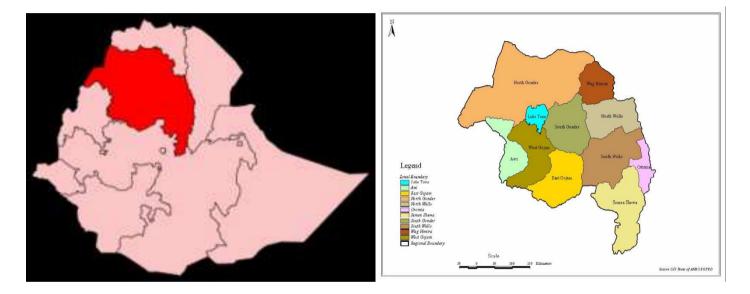
Kurukulasuriya, P., and Mendelsohn, R. (2008) Crop switching as a strategy for adapting to climate change, African Journal of Agricultural and Resource Economics, Volume 2, No. 1 (March), Pretoria.

Lang, G (2007) Where are Germany's gains from Kyoto? Estimating the effects of global warming on agriculture. Climate Change 84: 423-439

Lobell, David B. and Gregory P. Asner (2003) Climate and Management Contributions to Recent Trends in U.S. Agricultural Yields. Science 299:1032, 2003.

Maraun, D., F. Wetterhall, A. M. Ireson, R. E. Chandler, E. J. Kendon, M. Widmann. S. Brienen, H. W. Rust, T. Sauter, M. Theme V. K. C. Venema, K. P. Chun, C. M. Goodess, R. G. Jones, C. Onof, M. Vrac, and I. Thiele (2010). Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user. Review of Geophysics 48(3): 1-34.

Massetti, E.and R. Mendelsohn (2011) Estimating Ricardian Models With Panel Data, Climate Change Economics, Vol. 2(4): 301-319.

Mearns, LO, Easterling W, Hays C, Marx D (2001) Comparison of agricultural impacts of climate change calculated from high and low resolution climate change scenarios: Part I. The uncertainty due to spatial scale. Climatic Change51:131–172.

Mendelsohn, R. and A. Dinar (2009) Climate change and agriculture.An economic analysis of global impact, adaptation and distributional effects, Elgar, Cheltenham.

Mendelsohn RO, Nordhaus WD, Shaw D (1994): The Impact of Global Warming on Agriculture: ARicardian Analysis. American Economic Review, 84(4): 753-771.

Mendelsohn, R., A. Dinar, and L. Williams. 2006. "The Distributional Impact of Climate Change On Rich and Poor Countries" *Environment and Development Economics* **11**: 1-20

Mundlak, Y. 1978. On the Pooling of Time Series and Cross Section Data. *Econometrica* 46: 69-85.

Radha, V. Krishna Murthy (2004) Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. In Satellite Remote Sensing and GIS Applications in Agricultural Meteorology, volume AGM-8, 2004.

Rosenzweig, C., A. Iglesias, X.B. Yang, P. R. Epstein and E. Chivian (2009) Climate Change and Extreme Weather Events; Implications for Food Production, Plant Diseases, and Pests Global Change & Human Health. 2(2): 90-104.

Sachs, J., T. Panatayou, and A. Peterson (1999) Developing Countries and the Control of Climate Change: A Theoretical Perspective and Policy Implications. CAER II Discussion Paper, no. 44. Cambridge, MA, USA: Harvard Institute for International Development HII D.

Stage, J. (2010) Economic valuation of climate change adaptationin developing countries. Annals of the New York Academy of Sciences.1185 150–163 c_ 2010 New York Academy of Sciences.

Schlenker, Wolfram, and Michael J. Roberts.2009. Nonlinear Temperature Effects Indicate SevereDamages to US Crop Yields under Climate Change. Proceedings of the NationalAcademy of Sciences106 (37): 15594–8.

Schlenker, Hanemann, and Fisher (2006).The Impact of Global Warming on U.S.Agriculture: An Econometric Analysis of Optimal Growing Conditions. Review of Economics and Statistics, 88(1): 113-125, February 2006.

Schlenker, W. and M. Roberts (2006). Non Linear Effects of Weather on Corn Yields. Review of Agricultural Economics. 28: 391-398.

Seo, S.N., and R. Mendelsohn (2008a) Measuring Impacts and Adaptations to Climate Change: A Structural Ricardian Model of African Livestock Management. Agricultural Economics 38(2): 151-165.

Seo, S. N., and R. Mendelsohn (2008b) A Ricardian Analysis of The Impact of Climate Change Impacts on South American Farms. Chilean Journal of Agricultural Research 68: 69-79.

Stockle CO, Donatelli M, Nelson R (2003) CropSyst: a cropping systems simulation model. Eur J Agron18:289–307.

Timmins, C. (2006) Endogenous Land use and the Ricardian Valuation of Climate Change Environmental& Resource Economics, 33(1): 119-142.

Wooldridge, J.M. 2002. Econometric Analysis of Cross Section and Panel Data. MIT

Press, Cambridge, MA.

World Bank (2008a) Ethiopia: Climate Factsheet, Washington DC: World Bank, http://siteresources.worldbank.org/INTAFRICA/Resources/Ethiopia_Country_Note.pdf. Accessed 29 April 2010.

World Bank (2008b) Rural Households and Their Pathways Out of Poverty.In World Development Report 2008.http://siteresources.worldbank.org/INTWDR2008/-Resources-/2795087-1192112387976/WDR08_06_ch03.pdf. Accessed 23 February 2010.

Yu, Tian. Three Essays on Weather and Crop Yield.PhD thesis, Iowa State Univeristy, 2011.

Appendix A: A map of the study zones in the Amhara Region

Appendix B: The distribution of Educational and Physical Infrastructure, by Kebele***

Kebele	Primary school		Secondary school		Piped water		Community forest
	Availability	Sufficiency	Availability	Sufficiency	Availability	Sufficiency	Availability
Amanuel	Yes	Yes	Yes	Yes	Yes	No	Yes
Debre Elias	Yes	No	No	No	No	No	No
Kebi	Yes	Yes	No	No	No	No	No
Wolekie	Yes	Yes	No	No	No	No	No
Telima	Yes	No	No	No	Yes	No	Yes
Sekela Debir	Yes	No	No	No	Yes	No	Yes
Kete	Yes	No	Yes	Yes	Yes	No	No
Gudguadit	Yes	No	Yes	No	Yes	No	Yes
Amba Mariam	Yes	No	No	No	Yes	No	Yes
Yamed	Yes	Yes	Yes	No	Yes	Yes	Yes
Addis Mender	Yes	Yes	No	No	Yes	Yes	Yes
Chorisa	Yes	No	No	No	Yes	No	Yes

*** This information is based on the community level survey questionnaire.

Appendix C: T-test for mean differences in the distribution of short term temperature values between Amanuel kebele and the rest of the kebeles****

temperature	D. Elias	Kebi	Wolekie	Telima	Sekela Debir	Kete	Gudguadit	Amba Mariam	Yamed	Addis Mender	Chorisa
short term temperature (1°C-3°C)	-0.321	-5.324	-3.401	-1.568	-3.189	-11.752	-8.850	3.155	-1.324	0.449	-5.528
	(1.000)	(0.000)	(0.016)	(1.000)	(0.036)	(0.000)	(0.000)	(0.040)	(1.000)	(1.000)	(0.000)
short term temperature (4°C-6°C)	-3.187	.	.	-9.945	-5.057	-27.698	-23.361	-17.133	-17.563	-5.634	-12.032
	(0.035)	.	.	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
short term temperature (7°C-9°C)	0.413	-7.889	12.464	-30.574	-28.744	-21.993	-17.246	-18.436	-15.653	-33.474	-10.648
	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
short term temperature (10°C-12°C)	3.929	-11.398	6.916	3.451	3.318	18.372	14.640	16.243	18.864	13.061	15.756
	(0.002)	(0.000)	(0.000)	(0.014)	(0.023)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
short term temperature (13°C-15°C)	-2.211	2.924	-3.441	40.795	26.848	129.028	80.278	77.729	81.365	71.136	46.240
	(0.651)	(0.080)	(0.013)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
short term temperature (16°C-18°C)	-1.733	-1.561	-9.551	0.373	9.300	-13.798	-19.917	-16.720	-28.966	-19.094	-15.641
	(1.000)	(1.000)	(0.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
short term temperature (19°C-21°C)	-3.046	-1.364	-5.780	29.797	23.449	64.888	65.022	65.713	80.775	64.522	46.021
	(0.056)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
short term temperature (22°C-24°C)	1.780	9.405	-0.086	-8.987	0.891	30.887	14.989	8.904	5.630	2.113	2.408
	(1.000)	(0.000)	(1.000)	(0.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.833)	(0.402)
short term temperature (25°C-27°C)	-3.843	5.067	-11.336	-1.770	8.963	-69.651	-73.368	-63.033	-88.180	-82.007	-50.938
	(0.003)	(0.000)	(0.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
short term temperature (28°C-30°C)	-2.014	2.709	-3.227	-42.714	-26.734	-90.447	-72.524	-57.857	-70.370	-49.247	-43.063
	(1.000)	(0.156)	(0.029)	2.91e-317	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	2.38e-311
short term temperature (31°C-33°C)	-1.809	-1.881	-1.399	-24.068	-23.822	-79.049	-52.054	-35.775	-37.239	-40.112	-32.595
	(1.000)	(1.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

| short term temperature (34°C-36°C) | . | . | . | -2.538 | -3.279 | -21.341 | -16.712 | -17.539 | -20.398 | . | -10.656 |
| | . | . | . | (0.280) | (0.026) | (0.000) | (0.000) | (0.000) | (0.000) | . | (0.000) |

**** Figures in parenthesis are p-values

Appendix D: T-test for mean differences in the distribution of long term temperature values between Amanuel kebele and the rest of the kebeles****

temperature	Debre Elias	Kebi	Wolekie	Telima	Sekela Debir	Kete	Gudguadit	Amba Mariam	Yamed	Addis Mender	Chorisa
long term temperature (1°C-3°C)	4.184	-6.084	-3.945	16.257	11.689	6.736	8.078	13.776	14.556	11.999	11.481
	(0.001)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
long term temperature (4°C-6°C)	0.519	-5.138	-30.826	122.402	28.531	139.418	126.693	76.906	160.542	122.361	83.642
	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
long term temperature (7°C-9°C)	14.641	7.441	17.638	-24.525	-32.815	116.195	107.172	91.477	110.489	114.637	58.204
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
long term temperature (10°C-12°C)	8.586	-7.037	15.529	23.376	19.588	34.272	29.363	30.002	36.924	26.965	27.560
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
long term temperature (13°C-15°C)	-1.696	3.277	-1.264	34.912	20.710	133.155	91.891	84.042	94.484	88.709	50.058
	(1.000)	(0.024)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
long term temperature (16°C-18°C)	-1.518	-1.940	-11.132	-7.419	4.727	-20.561	-29.142	-21.112	-39.586	-28.854	-21.917
	(1.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
long term temperature (19°C-21°C)	0.339	1.914	-3.181	37.686	24.372	60.038	63.101	64.726	83.239	66.500	44.822
	(1.000)	(1.000)	(0.034)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
long term temperature (22°C-24°C)	-3.290	-1.335	-3.240	-30.087	-8.738	29.493	13.928	8.503	4.363	1.443	3.023
	(0.024)	(1.000)	(0.028)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(1.000)	(0.063)
long term temperature (25°C-27°C)	-7.262	-0.524	-15.512	-19.939	-3.113	-80.224	-99.136	-72.474	-114.281	-117.106	-58.125
	(0.000)	(1.000)	(0.000)	(0.000)	(0.047)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
long term temperature (28°C-30°C)	-7.977	0.820	-15.901	-98.456	-41.719	-110.666	-114.694	-83.553	-133.487	-120.618	-58.615
	(0.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
long term temperature (31°C-33°C)	-5.422	-4.042	-7.681	-108.516	-72.692	-141.849	-67.397	-103.731	-142.638	-123.182	-39.591
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

long term temperature (34°C-36°C)	2.254	5.262	-0.691	-41.510	-35.407	-23.726	9.287	85.430	102.263	147.284	39.083
	(0.582)	(0.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
long term temperature (>=37°C)	2.628	4.523	-6.331	-52.227	-59.935	-133.043	-67.885	-82.325	-85.675	-93.442	-33.984
	(0.207)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)