The impact of temperature shocks on households' saving behavior in rural Ethiopia

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Online appendix

A. More on conceptual framework: the linkage of temperature changes, risk & time preferences, and household saving

In order to develop a theoretical framework/model that shows how temperature shocks can affect household's saving behavior through effects on risk and intertemporal preferences, we follow specifications by Churchill *et al.* (2022) which start with a Constant Relative Risk Aversion utility function with endogenous risk and time preferences in which household *i* lives for two periods and drives utility from the two periods (C_{it} and $C_{i,t+1}$) as follows:

$$U\left(C_{it}, C_{i,t+1}\right) = \frac{{C_{it}}^{1-\theta(T_{it})}-1}{1-\theta(T_{it})} + E_t\left\{\beta(T_{it})\left(\frac{{C_{it+1}}^{1-\theta(T_{it})}-1}{1-\theta(T_{it})}\right)\right\}, \qquad \text{(A1)},$$

where T_{it} is the temperature parameter,[1] $\theta(T)$ is degree of relative risk aversion and $\beta(T)$ is the discounting factor[2] which is given by

$$\beta(T_{it}) = \left(\frac{1}{1+\rho(T_{it})}\right). \qquad \text{(A2)}$$

So as to capture the risk and time preferences linkage with temperature shocks, we further assume an exogenous income in the first (Y_{it}) and second period (Y_{it+1}). Hence, the budget constraint functions for period 1 and 2 respectively are as follows:

$$C_{it} = Y_{it} - S_{it} \qquad \text{(A3)}$$

$$C_{it+1} = Y_{it+1} + RS_{it}, \qquad \text{(A4)}$$

where S_{it} is savings in the first period and R is the exogenous interest reward on these savings.

Solving for the intertemporal budget constraint from Equations (A3) and (A4) yields

$$C_{it} = Y_{it} - \frac{C_{it+1} - Y_{it+1}}{R}. \qquad \text{(A5)}$$

[1] We specify $T_{it} = {T_i}^* + |x|$, where T^* long-run mean temperature, and x is either positive or negative deviation from this long-run mean.
[2] We anchor on the previous findings, which are thoroughly discussed in the main paper, to specify both degree of relative risk aversion and discounting factor as a function of temperature.

An individual in period t maximizes expected utility (Equation (A1)) subject to the intertemporal budget constraints (Equation (A5)) which yields Euler's equation, specified in Equation (A6),

$$C_{it}{}^{-\theta(T)} = \beta(T)R\, E_t\left(C_{it+1}{}^{-\theta(T)}\right). \tag{A6}$$

Substituting Equations (A2), (A3) and (A4) in Equation (A6), we have

$$C_{it}{}^{-\theta(T)} = \left(\frac{1}{1+\ \rho(T)}\right) R\, E_t\left([(Y_{it+1} + R(Y_{it} - C_{it})]^{-\theta(T)}\right). \tag{A7}$$

For exogenous income and interest rates, Equation (A7) implies that the optimal consumption, and in turn savings $(Y_{it} - C_{it})$ is determined by risk and time preferences, as shown in Equation (A8),

$$\frac{\partial S_{it}}{\partial T_{it}} = \frac{\partial S_{it}}{\partial T_{it}} \frac{\partial \rho_{it}}{\partial T_{it}} + \frac{\partial S_{it}}{\partial T_{it}} \frac{\partial \theta_{it}}{\partial T_{it}}\,. \tag{A8}$$

The first term on the right hand side of equation (A8) is the time preference channel whereas the second is risk preference.

Eckel *et al.* (2009) find that people have a greater appetite for risk after a natural shock. Cameron and Shah (2015), Cassar *et al.* (2017), Chantarat *et al.* (2019), and Beine *et al.* (2020) find that people become more risk-averse after a natural shock. Likewise, Callen (2015) and Chantarat *et al.* (2019) observe that after a negative natural shock, people become more patient, whereas Cassar *et al*. (2017), Di Falco *et al.* (2019), and Beine *et al.* (2020) find the opposite (i.e., people become more impatient).

B. More on the empirical model: specification and identification issues

The basic model we estimate to assess the effect of temperature shocks on household saving behavior is[3]

$$S_{it} = \beta_1 T_{it} + \beta_2 X_{it} + \pi_j + t_t + C_i + e_{it} \,. \tag{A9}$$

Following Dell *et al.* (2014)'s modification, we include adaptation to temperature change in our basic model (i.e., Equation (A9)) by taking the following step:

$$S_{it} = \beta_1 T_{it} + \mu T_{it} T_{i0} + \beta_2 X_{it} + \pi_j + t_t + C_i + e_{it}. \tag{A10}$$

The second term on the right side of Equation (A10) is what differentiates it from Equation (A9). While T_{it} is the same climate variable used in Equation (A9), the new term T_{i0} captures the long-run historical frequency with which a given temperature tends to occur (Dell *et al.*, 2014) that shows a fixed feature of place ***i.*** Dell *et al.* (2012) establish a coarser version of equation (A10) in which annual temperature shocks are interacted with a country's (in our case, a given EA's) long-run mean temperature.[4] The significance of coefficient μ suggests that individuals tend to adapt to climatic shocks (Dell *et al.,* 2014). Alternatively, a statistically significant coefficient μ indicates that the marginal effect of the shock is conditional on the long-run local climate, implying that identical shocks elicit different responses across locations with distinct climatic baselines. According to Dell *et al.* (2014) and Burke *et al.* (2015), such heterogeneity is compatible with adaptation to prevailing climate circumstances, whereby actors exposed to specific climatic regimes over time modify their behaviors, technology, or institutions to lessen the effects of recurrent shocks.

In order to assess whether or not shocks build over time, Dell *et al.* (2014) recommend that an estimate of the effect of a shock in year *t* will be different if shocks were experienced in the previous years. In this context, we can interact actual shocks with their own lags as follows:

[3] This equation is referred to as Equation (1) in the main document.

[4] Hence, according to Dell *et al.* (2014), the long-run mean temperature for each enumeration area (EA) is used to capture the long-run historical frequency of a certain temperature. This approach is supported by the fact that, within a given EA, the long-run mean offers the most likely predictor of the temperature for the following year in the absence of more accurate forecasts (Auffhammer *et al.,* 2013).

$$S_{it} = \beta_1 T_{it} + \sum_{p=t-k}^{t-1} \pi_p T_{it} \times T_{ip} + \beta_2 X_{it} + \pi_j + t_t + C_i + e_{it} . \qquad \text{(A11)}$$

The key coefficient for estimating intensification is π_p, which assesses the extent to which the impact of a given shock depends on the pattern of previous shocks (i.e, it examines whether past shocks have cofounding impacts or not). If the coefficient estimates are insignificant, it implies no evidence of shock intensification. Even in the case of significant coefficient estimates, declining magnitudes of π_p for earlier shocks is evidence of decaying away of impacts through time.

C. Appendix tables

Table A1. Impact of temperature shocks on household's saving behavior

Dep. Variable: Probability of HH saving	**Panel A: CRE estimation APE**	**Panel B: FE-logit estimation APE**	**Panel C: FE LPM estimation**
Explanatory variables	**Coeff.**	**Coeff.**	**Coeff.**
Standardized temperature deviations from LR(t)	*-0.014 (0.003)*	*-0.015 (0.002)*	*-0.014 (0.003)*
Standardized rainfall deviations from LR(t)	0.028 (0.105)	0.017 (0.029)	0.029 (0.107)
Experience of other shocks within a year (=1 if yes)	0.112 (0.052)	0.118 (0.046)	0.093 (0.072)
Basic financial knowledge (=1 if the household head has knowledge about various saving products in formal financial institutions-FFIs)	0.016 (0.017)	0.032 (0.033)	0.053 (0.032)
Distance to the nearest FFIs (in KM)	-0.01 (0.003)	-0.006 (0.003)	-0.01 (0.003)
Receipt of remittance (= 1 if a HH receives remittance either in cash or in-kind in a year)	-0.001 (0.031)	-0.053 (0.039)	-0.051 (0.04)
Ownership of off-farm income activity (= 1 if yes)	0.095 (0.022)	0.156 (0.033)	0.128 (0.029)
Marital status (Ref.: Divorced)			
Married	0.131 (0.052)	-	0.146 (0.067)
Single	0.123 (0.076)	-	0.145 (0.129)
Widow	0.079 (0.061)	-	0.132 (0.071)
Religion of HH head (=1 if Muslim)	-0.011 (0.032)	-	-
Age of HH head	0.009 (0.004)	0.011 (0.005)	0.014 (0.004)
Age squared	0.0001 (0.000)	0.0001 (0.000)	0.0002 (0.000)
Dependency ratio	0.0002 (0.001)	0.000 (0.001)	0.000 (0.001)
Year dummy (=1 for 2018)	-0.090 (0.069)	-0.119 (0.03)	-0.103 (0.07)

Regions (ref.: Afar)			
Amhara	-0.061 (0.046)	-	-
Oromia	-0.045 (0.044)	-	-
SNNPR	-0.012 (0.056)	-	-
Somali	-0.043 (0.038)	-	-
Tigray	0.039 (0.055)	-	-
Constant	-	-	0.450 (0.155)
Number of observations	2,872	1,412	2,872

Note: Values in parentheses are standard errors which are also clustered at 161 EAs.

Table A2. Long-run impacts of temperature shocks on household's saving behavior-CRE estimation and APE coefficients

Dep. Variable: probability of saving	**Adaption**	**Intensification**	
Explanatory variables	**Coeff.**	**Coeff.**	
Standardized temperature deviations from LR(t)	-0.014	-0.014	
	(0.004)	(0.004)	
Standardized temperature deviations from LR * LR mean temperature	0.0001		
	(0.000)		
Standardized temperature deviations from LR(t) *		-0.001	
Standardized temperature deviations from LR(t-1)		(0.003)	
Standardized temperature deviations from LR(t) *		0.003	
Standardized temperature deviations from LR(t-2)		(0.003)	
Standardized temperature deviations from LR(t)		-0.001	
Standardized temperature deviations from LR(t-5)		(0.004)	
Controls	Yes	Yes	
Number of observations	2,872	2,872	
Joint significance of current and lagged temperature interactions		*Chi2 (3)*	*1.95*
		F > chi2	*0.58*

Note: Controls include all those in Table A1, panel A. Values in parentheses are standard errors which are also clustered at 161 EAs.

Table A3. Impact of temperature shocks on mediator variables: FE-LPM estimation

Explanatory variables	**Risk preference**	**Time preference**	**Labor productivity**
	Coeff.	**Coeff.**	**Coeff.**
Standardized temperature deviations from LR	0.02	0.005	-0.15
	(0.006)	(0.003)	(0.048)
Other controls	Yes	Yes	Yes
Number of observations	2,872	2,872	2,872

Notes: Controls include all those in Table A1, panel C. Values in parentheses are standard errors which are also clustered at 161 EAs.

Table A4. Robustness estimation using alternative measures of temperature anomalies and temperature data source. Dependent variable is household's probability of saving - CRE estimation with APE coefficients

Panel A

Explanatory variables	Hot degree days	Cold degree days
	Coeff.	**Coeff.**
Degree days	-0.004	-0.033
	(0.002)	(0.021)
Other controls	Yes	Yes
Number of observations	2,872	2,872

NB: Controls include those variables in Table A1, panel A, except the mean values of hot and cold degree days are used in place of mean value of standard deviation of temperature in year *t.*

Panel B

Explanatory variables	Coeff.
Level deviation of actual temperature from LR	-0.012
	(0.002)
Other controls	Yes
Number of observations	2,872

NB: Controls include those variables in Table A1, panel A, except the mean value of level deviation is used in place of the mean value of standard deviation of temperature in year *t.*

Panel C

Explanatory variables	Coeff.
Standardized temperature deviations of *t*+1 (future weather) from LR	-0.06
	(0.04)
Other controls	Yes
Number of observations	2,872

NB: Controls include those variables in Table A1, panel A, except the mean value of standard deviation of temperature anomalies in *t*+1 is used in place of the mean value of standard deviation of temperature in year *t.*

Panel D

Explanatory variables	Coeff.
Standardized temperature deviations from LR	-0.01
	(0.003)
Other controls	Yes
Number of observations	2,872

NB: Controls include those variables in Table A1, panel A, except interactions of Year*Region fixed effect are used in above estimation.

Panel E

Explanatory variables	Coeff.
Standardized temperature deviations from LR	-0.004
	(0.002)
Other controls	Yes

Number of observations	2,872
NB: Controls include those variables in Table A1, panel A.	

Note: Values in parentheses are standard errors which are also clustered at 161 EAs.

Table A5. Robustness estimation of impact of temperature shocks using alternative measures of outcome variable

Panel A	
Dependent variable: Probability of saving from (Y-C)	**CRE Estimation-APE**
Explanatory variables	**Coeff.**
Standardized temperature deviations from LR	-0.004
	(0.002)
Other controls	Yes
Number of observations	2,872
Panel B	
Dependent variable: Amount of HH savings (Y-C) in logs	**FE-LPM estimation**
Explanatory variables	**Coeff.**
Standardized temperature deviations from LR	-0.002
	(0.001)
Other controls	Yes
Number of observations	2,872
Panel C	
Dependent variable: Self-reported amount of HH savings in logs	**FE-LPM estimation**
Explanatory variables	**Coeff.**
Standardized temperature deviations from LR	-0.08
	(0.02)
Other controls	Yes
Number of observations	2,872

Notes: Controls include all those in Table A1, panel A. Values in parentheses are standard errors which are also clustered at 161 EAs.

Table A6. Probit estimation of attrition bias in samples. Dependent variable is probability of attrition

Explanatory variables	**Coeff.**
Sex of the HH head	-0.189
	(0.225)
Family size	0.011
	(0.026)
Marital status (Ref.: Divorced)	
Married	-0.280
	(0.316)
Single	0.188
	(0.489)
Widow	-0.481
	(0.342)
Religion of HH head (=1 if Muslim)	0.039
	(0.129)
Age of HH head in years	0.113
	(0.039)
Age squared	-0.001
	(0.000)
Years of schooling completed by the HH	0.050
	(0.016)
Land size (in Ha.)	0.067
	(0.06)
Number of livestock (in TLU)	-0.026
	(0.02)
Number of active labor force in a household	-0.093
	(0.057)
Receipt of remittance (= 1 if a HH receives remittance either in cash or kind in a year)	0.096
	(0.164)
Ownership of off-farm income activity (= 1 if yes)	-0.271
	(0.161)
Distance to the nearest FFIs (in KM)	-0.015
	(0.015)
Constant	-3.948
	(1.000)
Number of observations	1,500
LR chi2(15)	30.81
Prob > chi2	0.009

Note: Values in parentheses are standard errors.

Table A7. Impact of temperature shocks on probability of household's saving after controlling for attrition, CRE estimation and APE coefficients

Dep. Variable: probability of saving	**Panel A: SIPW**	**Panel B: IMR**
Explanatory variables	**Coeff.**	**Coeff.**
Standardized temperature deviations from LR	-0.0135	-0.0135
	(0.003)	(0.003)
Stabilized Inverse Probability Weights (SIPW)	0.564	
	(0.346)	-
Inverse Mills ratio (IMR)		-0.059
	-	(0.043)
Other controls	Yes	Yes
Number of observations	2,872	2,872
Wald chi2(26)	228.74	228.96
Prob > chi2	0.0000	0.0000

Notes: Controls include all those in Table A1, panel A. Values in parentheses are standard errors which are also clustered at 161 EAs.

Table A8. Impact of temperature shocks on probability of saving using Conley SEs, CRE estimation and APE coefficients

Dep. Variable: probability of saving	**Panel A: 100 km cutoff distance**	**Panel A: 200 km cutoff distance**
Explanatory variables	**Coeff.**	**Coeff.**
Standardized temperature deviations from LR	-0.0138	-0.0138
	(0.0031)	(0.0034)
Other controls	Yes	Yes
Number of observations	2,872	2,872
Centered R2	0.063	0.063
Uncentered R2	0.617	0.617

Note: Controls include all those in Table A1, panel A.

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