Poverty Raises Levels of the Stress Hormone Cortisol: Evidence from Weather Shocks in Kenya*

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Abstract

Does poverty lead to stress? Despite numerous studies showing correlations between socioeconomic status and levels of the stress hormone cortisol, it remains unknown whether this relationship is causal. We used random weather shocks in Kenya to address this question. Our identification strategy exploits the fact that rainfall is an important input for farmers, but not for non-farmers such as urban artisans. We obtained salivary cortisol samples from poor rural farmers in Kianyaga district, Kenya, and informal metal workers in Nairobi, Kenya, together with GPS coordinates for household location and high-resolution infrared satellite imagery meausring rainfall. Since rainfall is a main input into agricultural production in the region, the absence of rain constitutes a random negative income shock for farmers, but not for non-farmers. We find that low levels of rain increase cortisol levels with a temporal lag of 10-20 days; crucially, this effect is larger in farmers than in non-farmers. Both rain and cortisol levels are correlated with self-reported worries about life. Together, these findings suggest that negative events lead to increases in worries and the stress hormone cortisol in poor people.

JEL Codes: C93, D03, D87, O12

Keywords: weather shocks, rainfall, cortisol, stress, worries

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1 Introduction

The economic consequences of poverty are well-known; however, the psychological consequences have received less attention. In recent years, a small literature has emerged that asks whether poverty also has psychological and neurobiological consequences. A prominent hypothesis in this domain is that poverty may lead to increases in stress, and in particular the stress hormone cortisol. This hypothesis is supported by several lines of evidence. First, recent work in the psychology and economics of happiness has documented a robust relationship between income and happiness, both within and across countries: poor people are less happy and satisfied with their lives than rich people in the same country; in addition, people in richer countries are, on average, happier than people in poorer countries (Stevenson and Wolfers 2008). Conversely, the prevalence of depression in developing countries is staggering: while the prevalence rates in Europe and North America hover between 5-10%, developing countries report numbers such as 19% (Lebanon, Mexico), 20% (Thailand), 24% (Uganda), 39% (Dominican Republic) and 40% (Cuba; Thavichachart et al. 2001; Sobocki et al. 2006; Patel et al. 2003; Bolton et al. 2002; Bolton et al. 2004; Garcia-Alvarez 1986). This finding supports the putative relationship between poverty and stress because stress is a significant factor in the etiology of depression: 80% of all patients with depression have histories of chronic stress or stressful life events (Hammen 2005), and depression is marked by dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis, which controls the release of cortisol (Holsboer 2000). Finally, a number of authors have argued that low-income environments may be characterized by both greater exposure to stressful events, and the absence of resources to deal with such stress (Baum et al. 1999; Steptoe et al. 2002; Brunner 1997; Kristenson et al. 2004).

Together, these strands of literature suggest that poverty may be characterized by increased levels of stress, and in particular the stress hormone cortisol. Indeed, this relationship has been confirmed in a number of studies which find significant correlations between socio-economic status (SES), self-reported stress, and cortisol (Cohen et al. 2006; Evans and English 2002; Evans and Kim 2007; Lupien et al. 2011; Li et al. 2007; Lupien et al. 2000; Arnetz et al. 1991; see Dowd et al. 2009 for a review). However, these studies were conducted in developed countries; it remains unclear whether a similar relationship exists in developing countries. More importantly, these findings are merely correlational and therefore do not justify conclusions about whether poverty causes stress, or vice-versa.

The present paper aims to fill this gap. We exploit the fact that rainfall is an important input to production for farmers, but not for certain other professions such as urban artisans. Thus, the absence of rain potentially precedes a decrease in income for farmers, but less so for artisans, and thus allows us to identify a causal effect of weather shocks on respondents' levels of the stress hormone cortisol and their worries about life. Specifically, obtain cortisol samples from farmers and non-farmers in Kenya, and combine this data with high-resolution satellite rainfall data and with household-level GPS data. We find that farmers have higher levels of cortisol, and report more worries about their lives, if the previous 10-20 days brought low amounts of rain; importantly, this effect is significantly larger for farmers than for non-farmers. Our findings establish a causal relationship between weather shocks, worries, and neurobiological markers of stress.

2 Methods

2.1 Subjects and Setting

We studied 283 Kikuyu farmers (113 women) in Kianyaga district, Kenya, and 896 urban metal workers (93 women) in Nairobi, Kenya, between January 2010 and March 2012. Each participant gave written consent; illiterate participants gave consent by fingerprint. The study was approved by the ethics commissions at the University of Zurich, McGill University, Innovations for Poverty Action Kenya (IPAK), and the Kenya Medical Research Institute (KEMRI). Participants received KES 200 (USD 1.20) for participation; in addition, they could earn money in the economic games that were part of the questionnaire.

2.2 Procedure

Households were chosen randomly based on household lists obtained from village elders in Kinayaga, and based on a list of members of the informal workers' association of the Kamukunji Jua Kali area, Nairobi. Data were collected in one-on-one field interviews at the respondents' homestead (Kianyaga) or workplace (Nairobi) by trained enumerators. In Kianyaga, interviews were conducted in Kikuyu; in Naiorbi, they were conducted in Swahili. To ensure accurate translations of the questionnaire, it was translated into Kikuyu and Swahili by four different translators, and then back-translated into English by another four translators. The four back-translated versions were then compared to the English originals, and the team of 8 translators plus one supervisor agreed on a final translation.

At the beginning of the interview, the consent script was read and consent was obtained by signature or thumbprint. Respondents were paid after completing the interview. Saliva samples were obtained before and after the interview.

Questionnaire and GPS data

We administered a standard socioeconomic questionnaire that elicited information about household structure, income, education, health, and current worries. The questionnaire was administered for insurance projects run by the authors. Interviews took place between January 2010 and March 2012, and the order in which each household was visited was randomzied. The crucial questionnaire data for the purpose of this paper are respondents' levels of worries. We asked respondents, "How worried are you about the following areas of your life, on a scale from 1-4, where 1 means 'not at all worried', and 4 means 'very worried'?" The 14 areas about which respondents were asked were health problems/illness, problems at home or with relatives, problems in the workplace, accidents and disasters, ethnic tensions, not enough money for food, education, living expenses, medicines and treatments, difficulty finding work, idleness of children or spouse, alcohol consumption of children or spouse, death of a family member, debts owed to others. The responses to the 14 items were averaged for each respondent, yielding an average score between 1-4, and then z-scored.

At the same time as the questionnaire was administered, the GPS coordinates of the households in Kianyaga were collected using a handheld GPS device, and recorded in degrees of latitude and longitude, at a resolution of 1/1000th of an arcminute, which corresponds to ~0.18 meters at this proximity to the equator. In Nairobi, all respondents are located within a 0.5 x 0.5 km area, and thus the same GPS location was used for all households in this location; the identification comes from temporal variation.

Rainfall data

Rainfall data were obtained from the Famine Early Warning Systems Network, FEWSNET (www.fews.net). The data were originally downloaded in ArcGIS format, and then transferred into Stata format using a custom-written FORTRAN program. The data are provide a rainfall estimate based on high-resolution Meteosat infrared data, rain gauge reports from the global telecommunications system, and microwave satellite observations. The data cover the years 2000-2011; for the purpose of this study, the relevant time frame is from 20 days before our surveys began until they ended (see below for choice of lag for the rain timeseries), i.e. December 2009 – December 2010. The data are dekadal, i.e. averaged over 10-day intervals. The spatial resolution is 0.1°, which corresponds to 11 km at this proximity to the equator. To obtain household-specific rainfall data, we identified the four closest gridpoints in the rainfall data based on the GPS location of each household, and then used bilinear interpolation to compute a weighted rainfall average for that household, separately for each dekad from t-1 to t-20, i.e. from 10 to 200 days into the past relative to the date of the survey. This yielded a rainfall estimate that was unique to each household, for each 10-day interval in the study period. In Nairobi, the coordinates of the center of the 0.5 x 0.5 are in which respondents have their workplaces were used as the GPS location for all respondents.

Salivary cortisol

Cortisol is the body's major stress hormone. It is synthesized by the hypothalamic-pituitary-adrenal (HPA) axis: in response to external stressors, the hypothalamus in the midbrain secretes corticotrophin-releasing hormone (CRH), which in turn controls the release of adrenocorticotropic hormone (ACTH) from the pituitary gland; ACTH then causes the release of cortisol from the adrenal gland. Two factors give cortisol its prominent role in stress: first, it is released in response to both psychological and physiological strain on the organism (Kirschbaum and Hellhammer 1989). In the physical domain, it increases following bodily injuries, physical exertion, illness, and extreme temperatures. In the psychological domain, cortisol increases in response to social stressors such as having to give a speech in front of a panel of judges, performing mental arithmetic, or enduring physically unpleasant situations like immersion of one's hand in cold water (Kirschbaum et al. 1993; Ferracuti et al. 1994).

Second, cortisol in turn has effects on the body that one would expect from a stress hormone; in particular, it increases blood sugar to levels that prepare the organism to deal with stress. Moreoever, cortisol exerts a direct and broadly suppressive effect on the immune system; in particular, it suppresses pro-inflammatory cytokines such as interleukin-6 and interleukin-1 (Straub 2006; Wilckens 1995). However, chronic elevations of cortisol appear to have the opposite effect, leading to permanent mild elevations of cytokine levels (Kiecolt-Glaser et al. 2003). These cytokine elevations then contribute directly to disease onset and progression, e.g. in atherosclerosis and cancer (Steptoe et al. 2002; Steptoe et al. 2001; Aggarwal et al. 2006; Coussens et al. 2002). Thus, while transient cortisol elevations are adaptive and protective, permanently high cortisol is physiologically damaging, quite apart from the psychological effects.

To measure cortisol levels in our respondents, we obtained salivary samples using Salivette sampling devices (Sarstedt, Nümbrecht, Germany), once before and once after questionnaire administration. Salivary samples were stored at room temperature for at most 10 days, and then transported to Nairobi, where they were stored at -20°C until further analysis. Free cortisol levels were measured at Lancet Pathologists, Nairobi. In a blinded test of this laboratory with duplicate samples, the correlation across sample pairs was $r = 0.995$ (N=60). Free cortisol is the physiologically active component of cortisol, and is closely related to the rate of cortsiol secretion by the adrenal gland (Kirschbaum and Hellhammer 1989; Aardal and Holm 1995; Aardal-Eriksson et al. 1998). During analysis, the two samples were average to obtain more stable estimates of cortisol levels. Salivary cortisol levels are subject to a number of confounds; in particular, eating, drinking coffee, tea, or alcohol, consuming miraa (khat), and engaging in strennuous physical activity can bias cortisol levels; we therefore control for these variables in our regressions. To this end, participants answered in the questionnaire whether they engaged in any of these activities earlier on the day of the interview, and a dummy variabile was created for each activity.

2.3 Statistical analysis

Autoregressive Order Selection and Timeseries Order of Integration

The rainfall data is likely to contain serial correlation, which we model as an autoregressive process. We use information criteria to choose the most appropriate autoregressive order for the rainfall process. We report both the Akaike Information Criterion (Akaike 1973; Akaike 1974; Akaike 1978) and Schwarz's Bayesian information criterion (SBIC; Schwarz 1978).

To ensure stationarity of the time series, we test for the presence of a unit root using the augmented Dickey-Fuller Test (Elliott et al. 1996). The absence of a unit root implies stationarity of the time series and integration of order 0. The null hypothesis of the Dickey-Fuller test is the presence of a unit root; a large negative value rejects this hypothesis. We perform the test using the autoregressive order determined with information criteria, both with and without lag and drift terms.

Regression Specifications

To assess the effect of rainfall shocks on cortisol levels separately for farmers and non-farmers, we run the following regression separately for each group:

$$
\begin{aligned}
y_{i,t} = {} & \beta_0 + \beta_1 rain_{i,t-1} + \beta_3 \mathbf{X_i} + \beta_4 female_i + \beta_5 female_i \cdot rain_{i,t-1} + \beta_6 plantingseason_{t-1} \\
& + \beta_7 plantingseason_{t-1} \cdot rain_{i,t-1} + \beta_8 female_i \cdot plantingseason_{t-1} \\
& + \beta_9 female_i \cdot plantingseason_{t-1} \cdot rain_{i,t-1} + \alpha_M + \gamma_G + u_{i,t}
\end{aligned}
$$

where the outcome variable $y_{i,t}$ is either an individual's cortisol levels, or their life worries; t is the dekad subscript and i the household subscript; $rain_{i,t}$ is the household-specific rainfall measure at time t; $female_i$ is a gender dummy; $\mathbf{X_i}$ is a vector of cortisol control variables (see above); α_M and γ_G are month-of-the-year and rainfall-grid fixed effects; $u_{i,t}$ is the error term; and $plantingseason_{t-1}$ is a dummy variable indicating whether rainfall one dekad ago would have fallen within the planting season. Based on the agricultural properties of the region around Kinayaga, we defined the short rains planting season as the months of September and October, and the long rains planting season as the months of March and April. Modeling rainfall as an AR(1) process reflects the results from the autoregressive order selection procedure, reported below. We use heteroskedasticity-robust standard errors. The coefficient of interest in this specification is that on the rainfall measure at $t-1$: if negative weather shocks contribute to stress and raise cortisol levels, we should observe negative coefficients on this variable. Importantly, this effect should be stronger in farmers than in non-farmers, because for the former rainfall constitutes an important input to production. We further predicted that the effect of rain on cortisol levels and worries should be particularly pronounced among farmers in the planting season, when rain is of critical importance to agricultural production.

To directly test whether the effect of rainfall on cortisol levels and worreis is more pronounced among farmers than non-farmers, we use the following specification:

$$
\begin{aligned}
y_{i,t} = {} & \beta_0 + \beta_1 rain_{i,t-1} \cdot farmer_i + \beta_2 rain_{i,t-1} + \beta_3 farmer_i + \beta_4 \mathbf{X_i} + \beta_5 female_i \\
& + \beta_6 female_i \cdot rain_{i,t-1} + \beta_7 plantingseason_{t-1} + \beta_8 plantingseason_{t-1} \cdot rain_{i,t-1} \\
& + \beta_9 female_i \cdot plantingseason_{t-1} + \beta_{10} female_i \cdot plantingseason_{t-1} \cdot rain_{i,t-1} \\
& + \beta_{11} farmer_i \cdot plantingseason_{t-1} + \beta_{12} farmer_i \cdot plantingseason_{t-1} \cdot rain_{i,t-1} + \alpha_M + \gamma_G + u_{i,t}
\end{aligned}
$$

Here, all variables are as above; $farmer_i$ is a dummy variable indicating whether the respondent is a farmer (Kianyaga) or a non-farmer (Nairobi). The main coefficient of interest is β_1, because it tests directly whether the effect of rainfall on cortisol is more pronounced among farmers than among non-farmers.

3 Results

Our question was whether lack of rainfall would increase levels of cortisol and worries, and whether this increase is larger for farmers than for non-farmers. We study this question in the Kianyaga district of Kenya, on the slopes of Mt. Kenya, a region populated by Kikuyu people whose household income and consumption depends heavily on agriculture, and thus, rain; and in an informal workers' area of Nairobi, where respondents are mostly metal workers and therefore depend much less on rainfall for their livelihood. (Note, however, that many of the respondents in Nairobi may have family in rural areas, and so we might expect at least a moderate effect of a lack of rainfall on their cortisol levels. We nevertheless use rainfall in Nairobi for this group of respondents because our main concern is with rainfall in the location where the respondent earns a living; however, this measure may also proxy for rainfall in respondents' home regions, which tend to be close to Nairobi and are likely to be correlated with Nairobi in terms of rainfall patterns.) For farmers, small fluctuations in rainfall can have potentially serious adverse consequences for the harvest and hence household welfare; we therefore hypothesized that fluctuations in rainfall would lead to stress among farmers, reflected in increased levels of cortisol and worries, and that this effect would be larger in farmers than in non-farmers.

We therefore regressed cortisol levels on lagged values of rainfall data obtained from FEWSNET satellite imagery. We first analyzed the autoregressive order of the rainfall timeseries using information criteria. Specifically, we computed the Akaike Information Criterion and Schwarz's Bayesian Information Criterion for the timeseries of dekadal rainfall indices, up to a maximum lag of 20 dekads (200 days). Table 1reports the AIC and SBIC values resulting from this analysis. Both information criteria are minimized at lag 1. In the following we therefore regress cortisol on rainfall for the current and one previous dekad.

Second, to ascertain that the rainfall timeseries is stationary, we performed different versions of the augmented Dickey-Fuller test on the data. The results are shown in Table 2. The null hypothesis was rejected in all cases, suggesting that the rainfall timeseries is stationary.

These results put us in a position to address our main question of interest: does lack of rain predict cortisol levels 10-20 days later? Figure 1 shows graphically that this appears to be the case: cortisol levels decrease in rainfall among farmers, but less so among non-farmers. Econometrically, we address this question with regressions of cortisol levels on lagged rainfall, separately for farmers and non-farmers. Table 4 reports the results form this regression for farmers, Table 4 for non-farmers. Column 1 reports a basic specification; column 2 includes month and location fixed effects; and columns 3-5 include various sets of control variables. For farmers, the coefficients on the rainfall variable are negative and highly significant in all specifications. For non-farmers, we also observe a negative effect of rainfall on cortisol levels, but the results are weaker: not all specifications are significant, and more importantly, the magnitude of the effect is only a small fraction of that observed for farmers. Specifically, our various sepcifications estimate the effect of rain on cortisol among non-farmers at 16%, 8%, 7%, 2%, and 0.7% the magnitude of the effect on farmers.

This result suggests that lack of rainfall indeed leads to higher cortisol levels, and that this effect is more pronounced among farmers, who depend on rain for their livelihood, than among non-farmers. In terms of magnitude, in our preferred specification (Tables 4 and 4, column 5), we found that a 10mm decrease in rainfall in the previous dekad leads to a cortisol increase of 17.6 nmol/l among farmers; from a baseline of 35.4 nmol/l, this corresponds to a 49.7% increase. Thus, lack of rain has a strong and temporally contiguous effect on the cortisol levels of farmers. In contrast, among non-farmers, a 10mm decrease in rainfall in the previous dekad was assocaited with a significant, but much smaller cortisol increase of 0.1 nmol/l; from a baseline of 14.5 nmol/l, this corresponds to a 0.7% increase.

To directly test whether the absence of rain has a greater effect on cortisol levels among farmers, who depend on rain for their livelihood, than among non-farmers, we next ran regressions on the entire sample of respondents which included a dummy variable for whether or not the respondent was a farmer. The main coefficient of interest is the interaction between $farmer_i$ and $rain_{i,t-1}$: a significantly negative coefficient on this interaction would indicate that the negative effect of rainfall on cortisol levels is significantly more pronounced among farmers than among non-farmers. The results of this regression are reported in Table 4. All coefficients on the interaction between $farmer_i$ and $rain_{i,t-1}$ are negative and highly significant. Our preferred specification (column 4) suggests that a 10mm decrease in rainfall in the previous dekad leads to a cortisol increase that is 6.91 nmol/l *larger* among farmers than among non-farmers; on a baseline of 19.50 nmol/l, this corresponds to a 35% increase.

We next asked whether lack of rain also has psychological consequences. Figure 2 shows graphically that among farmers, the level of worries tends to be higher when rainfall is low; in contrast, no such effect can be seen among non-farmers. To quantify this observation, we regressed the "worries" variable on rainfall in the previous dekad, separately for farmers and non-farmers. The results are shown in Tables 4 and 4. For farmers, again the coefficients on the rainfall variable are negative and significant in the most conservative specifications, including our preferred specification (Table 4, column 5). In contrast, we observe no significant relationship between rainfall and worries among non-farmers. These results suggest that lack of rainfall leads to an increase in worries in our sample of Kikuyu farmers, but not among Nairobi artisans. However, even among farmers the effect is relatively small in magnitude: a 10mm decrease in rainfall in the previous dekad leads to an increase in worries of 0.02 standard deviations.

To directly test whether the effect of rain on worries is larger among farmers than among non-farmers, we employ the same strategy as above and include a dummy variable for whether or not the respondent is a farmer in the regression. The coefficient of interest is again that on the interaction between $farmer_i$ and $rain_{i,t-1}$. The results are shown in Table **??**. All coefficients on the interaction between $farmer_i$ and $rain_{i,t-1}$ are negative, and all but one of them are significant, suggesting that a lack of rain leads to an increase in worries that is more pronounced among farmers than among non-farmers. Note, however, that this effect only reaches significance at the 10% level, and that it is small in terms of magnitude; a 10mm decrease in rainfall in the previous dekad is associated with an increase in worries that is

0.08 standard deviations greater among farmers than among non-farmers.

4 Discussion

In this paper we asked the question whether increases in poverty lead to stress, measured here by the stress hormone cortisol, and by self-reported worries about life. We find that weather shocks in the form of lack of rain indeed appear to cause stress: in a sample of 1179 respondents in Kenya, we combine cortisol measures with household-level GPS data and high-resolution satellite rainfall data, and find that lack of rain leads to a strong increase in cortisol levels, and a moderate increase in self-reported worries, with a lag of 10-20 days. Importantly, this effect is more pronounced among farmers, who depend on rainfall for their livelihood, than among non-farmers. These results suggest that random exogenous shocks to households' economic situations through weather shocks cause substantial increases in neurobiological and psychological markers of stress.

These results contribute to the emerging literature on the relationship between stress and income/socioeconomic status by showing that this relationship is causal. A growing number of studies have documented that poor and otherwise disadvantaged people show increased levels of cortisol (Cohen et al. 2006; Evans and English 2002; Evans and Kim 2007; Lupien et al. 2011; Li et al. 2007; Lupien et al. 2000; Arnetz et al. 1991; Dowd et al. 2009); however, to date this relationship has been identified through correlation, leaving it unclear in which direction causality runs. One could easily imagine it going in both directions: the idea that poverty can cause stress is uncontroversial; conversely, however, it is also possible that stressed individuals are more likely to end up in poverty, e.g. through impaired job performance due to stress. The contribution of this study is to provide causal evidence for the first channel, i.e. the effect of poverty on stress.

In providing evidence for a causal effect of poverty on stress, our study is similar to two recent studies that have also attempted to resolve this correlation-causation dilemma in the opposite direction, namely by measuring the impacts of development programs on stress levels. Fernald and Gunnar 2009 measured cortisol levels in children who had been exposed to the Mexican PROGRESA program – a comprehensive conditional cash transfer program with a focus on health and education. The authors found that children who had been exposed to the program exhibited lower baseline cortisol levels than those children who had not been in the program. In another study, Fernald et al. 2008 investigated responses to stress and depression questionnaires in a sample of South-African respondents after they were randomly assigned to receive a loan. Those who had received loans showed lower levels of depressive symptoms than the control group; interestingly, however, questionnaire-assessed stress levels were higher after receiving a loan than in the control group, possibly due to the stress induced by having to pay back the loan at a high interest rate (200% p.a.). Thus, these previous programs studied the effects of poverty decreases on stress levels; note though that one was in children and the other did not measure stress using cortisol. Our study contributes by showing a significant causal effect of poverty on stress in the other direction, namely through weather shocks to agricultural productivity, and by providing cortisol evidence from adults rather than children.

Several caveats are in order. A potential concern is that respondents who experienced weather shocks may have to perform more strenuous physical activity to make up for the adverse climatic conditions, and that our cortisol results reflect this physical strain as opposed to psychological stress. However, we deem this account unlikely for two reasons. First, controlling for whether the respondent performed strenuous physical activity prior to the interview did not alter the results. Second, the effect would be predicted to go in the opposite direction: farmers in this region work harder when it rains compared to when it does not rain – simply put, there is nothing to do without rain. Thus, on this account we should observe an increase in cortisol levels after rain, rather than the decrease that we actually observe.

In addition, the present study raises a number of questions for follow-on work. In particular, we study the effect of exogenous increases in poverty on cortisol levels; it remains unclear whether decreases in cortisol have the converse effect, and could therefore be used as potential stress alleviation interventions. As mentioned above, Fernald and Gunnar 2009 showed that Mexican children whose mothers had been exposed to the Progresa program in Mexico show lower cortisol levels than comparison children; however, it is not clear which of the program's many interventions accounts for this effect, and it remains unknown to what extent selection of mothers into the study could be responsible for it. In addition, data on the effect of poverty alleviation programs on the cortisol levels of adults is not available. We are currently conducting two randomized controlled trials in Kenya, one on health insurance and one on unconditional cash transfers, which will address these issues.

The present study is the first addressing the relationship between poverty and stress in a developing country. This is somewhat surprising as existing data on the prevalence of stress and depression suggest that developing countries are particularly affected; we therefore hope that significantly more effort will be dedicated in the future on elucidating the causes and consequences of this fact, and on developing interventions to alleviate the problem.

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Lag	AIC	SBIC
0	8.567	8.603
1	*8.466	*8.537
2	8.479	8.586
3	8.513	8.656
4	8.518	8.696
5	8.528	8.742
6	8.553	8.802
7	8.587	8.871
8	8.616	8.935
9	8.650	9.005
10	8.646	9.036
11	8.671	9.098
12	8.706	9.168
13	8.728	9.225
14	8.759	9.292
15	8.788	9.356
16	8.810	9.413
17	8.842	9.482
18	8.857	9.532
19	8.811	9.522
20	8.842	9.589

Table 1: Lag order selection statistics for rainfall in Kianyaga district. The columns show Akaike Information Criterion (AIC) and Schwarz's Bayesian Information Criterion (SBIC) values for the dekadal rainfall variable at 0.5°N 37.3°E, which is the grid corresponding to the centroid of the GPS household locations. Both information criteria are minimzed at lag 1.

Specification	Statistic	Rainfall
Basic	Z	-6.042
	P	0.000
With trend	Z	-6.066
	P	0.000
With drift	Z	-6.042
	P	0.000

Table 2: Results of the augmented Dickey–Fuller test for the rainfall time-series in Kianyaga district. The trend specification includes a trend term in the associated regression, and assumes that the process under the null hypothesis is a random walk (possibly with drift). The drift specification assumes that the process under the null hypothesis is a random walk with nonzero drift. Significantly negative test statistics are evidence for stationarity.

Table 3: Effect of Rain on Cortisol, Farmers

	(1)	(2)	(3)	(4)	(5)
	cort	cort	cort	cort	cort
Rain (t-1)	-0.566***	-1.621**	-1.654**	-1.744**	-1.760**
	(0.144)	(0.704)	(0.714)	(0.805)	(0.807)
Female			-4.465		-4.104
			(9.379)		(9.639)
Rain (t-1) x Female			0.236		0.211
			(0.420)		(0.427)
Planting season				77.86	93.65
				(65.62)	(65.05)
Rain (t-1) x Planting season				-5.808	-7.036*
				(3.832)	(3.771)
Rain (t-1) x Female x Planting season					0.464
					(0.587)
Constant	39.87***	32.39	35.39	39.67	41.67
	(4.325)	(47.66)	(49.65)	(52.84)	(53.98)
Cortisol controls	No	Yes	Yes	Yes	Yes
Location FE	No	Yes	Yes	Yes	Yes
Month FE	No	Yes	Yes	Yes	Yes
N	283	283	283	283	283

Effect of rain in past dekad (t-1) on cortisol levels in farmers.
Cortisol controls include dummies for recent eating, smoking, drinking coffee or tea, performing intense physical activity, taking medication, or chewing miraa earlier on the same day. Location and month fixed effects control for grid within the rainfall data and month of the year, respectively. Robust standard errors in parentheses.
* $p < 0.10$, ** $p < 0{:}05$, *** $p < 0.01$.

Table 4: Effect of Rain on Cortisol, Non-farmers

	(1)	(2)	(3)	(4)	(5)
	Cortisol	Cortisol	Cortisol	Cortisol	Cortisol
Rain (t-1)	-0.0931***	-0.123***	-0.109**	-0.0314	-0.0114
	(0.0251)	(0.0435)	(0.0454)	(0.0739)	(0.0784)
Female			1.346		1.510
			(4.255)		(4.274)
Rain (t-1) x Female			-0.119		-0.135
			(0.0860)		(0.106)
Planting season				9.744*	9.858**
				(5.011)	(5.004)
Rain (t-1) x Planting season				-0.0635	-0.0744
				(0.0889)	(0.0927)
Rain (t-1) x Female x Planting season					0.0244
					(0.0599)
Constant	16.07***	15.94*	23.39	22.46	22.12
	(1.180)	(8.843)	(21.61)	(21.26)	(21.21)
Cortisol controls	No	Yes	Yes	Yes	Yes
Month FE	No	Yes	Yes	Yes	Yes
N	897	892	892	892	892

Effect of rain in past dekad (t-1) on cortisol levels in Nairobi.
Cortisol controls include dummies for recent eating, smoking, drinking coffee or tea, performing intense physical activity, taking medication, or chewing miraa earlier on the same day. Month fixed effects control for month of the year.
Robust standard errors in parentheses.
* $p < 0.10$, ** $p < 0{:}05$, *** $p < 0.01$.

Table 5: Effect of Rain on Cortisol, entire sample

	(1) Cortisol	(2) Cortisol	(3) Cortisol	(4) Cortisol
Rain (t-1) x Farmer	-0.473***	-0.572***	-0.666***	-0.691***
	(0.146)	(0.198)	(0.203)	(0.200)
Rain (t-1)	-0.0931***	-0.128***	-0.120**	-0.0435
	(0.0251)	(0.0469)	(0.0486)	(0.0871)
Farmer	23.79***	25.73	26.44*	25.90*
	(4.475)	(15.70)	(15.64)	(15.46)
Female			-1.379	-1.299
			(4.705)	(4.726)
Rain (t-1) x Female			-0.0463	-0.0480
			(0.107)	(0.107)
Planting season				7.312
				(4.839)
Rain (t-1) x Planting season				-0.0597
				(0.0987)
Rain (t-1) x Female x Farmer			0.295	0.204
			(0.226)	(0.213)
Rain (t-1) x Farmer x Planting season				1.950***
				(0.460)
Constant	16.07***	15.82	20.49	16.72
	(1.180)	(12.02)	(12.86)	(13.83)
Cortisol controls	No	Yes	Yes	Yes
Location FE	No	Yes	Yes	Yes
Month FE	No	Yes	Yes	Yes
N	1180	1175	1175	1175

Effect of rain in past dekad (t-1) on cortisol levels in Nairobi and Kianyaga. Cortisol controls include dummies for recent eating, smoking, drinking coffee or tea, performing intense physical activity, taking medication, or chewing miraa earlier on the same day. Location and month fixed effects control for grid within the rainfall data and month of the year, respectively. Robust standard errors in parentheses.
* $p < 0.10$, ** $p < 0{:}05$, *** $p < 0.01$.

Table 6: Effect of Rain on Worries, Farmers

	(1)	(2)	(3)	(4)	(5)
	Worries	Worries	Worries	Worries	Worries
Rain (t-1)	-0.00408	-0.00791	-0.00928	-0.0118**	-0.0127**
	(0.00280)	(0.00574)	(0.00574)	(0.00560)	(0.00553)
Female			0.142		0.143
			(0.108)		(0.110)
Rain (t-1) x Female			0.00836		0.00670
			(0.00659)		(0.00670)
Planting season				1.018	1.640
				(1.631)	(1.928)
Rain (t-1) x Planting season				-0.0875	-0.136
				(0.106)	(0.142)
Rain (t-1) x Female x Planting season					0.0184
					(0.0348)
Constant	1.500***	2.940***	3.111***	3.174***	3.304***
	(0.0448)	(0.424)	(0.438)	(0.431)	(0.443)
Cortisol controls	No	Yes	Yes	Yes	Yes
Location FE	No	Yes	Yes	Yes	Yes
Month FE	No	Yes	Yes	Yes	Yes
N	307	307	307	307	307

Effect of rain in past dekad (t-1) on worries in Kianyaga.
Cortisol controls include dummies for recent eating, smoking, drinking coffee or tea, performing intense physical activity, taking medication, or chewing miraa earlier on the same day. Location and month fixed effects control for grid within the rainfall data and month of the year, respectively. Robust standard errors in parentheses.
* $p < 0.10$, ** $p < 0{:}05$, *** $p < 0.01$.

Table 7: Effect of Rain on Worries, Non-farmers

	(1) Worries	(2) Worries	(3) Worries	(4) Worries	(5) Worries
Rain (t-1)	0.000580	-0.000110	-0.0000774	-0.00144	-0.000987
	(0.000685)	(0.000876)	(0.000909)	(0.00146)	(0.00152)
Female			0.0512		0.0513
			(0.0605)		(0.0600)
Rain (t-1) x Female			-0.000428		-0.00304
			(0.00242)		(0.00277)
Planting season				-0.0921	-0.0898
				(0.0633)	(0.0633)
Rain (t-1) x Planting season				0.00166	0.00101
				(0.00192)	(0.00197)
Rain (t-1) x Female x Planting season					0.00483
					(0.00365)
Constant	-0.514***	-0.660**	-0.679**	-0.568*	-0.600*
	(0.0180)	(0.329)	(0.339)	(0.336)	(0.350)
Cortisol controls	No	Yes	Yes	Yes	Yes
Month FE	No	Yes	Yes	Yes	Yes
N	899	894	894	894	894

Effect of rain in past dekad (t-1) on worries in Nairobi.
Cortisol controls include dummies for recent eating, smoking, drinking coffee or tea, performing intense physical activity, taking medication, or chewing miraa earlier on the same day. Month fixed effects control for month of the year.
Robust standard errors in parentheses.
* $p < 0.10$, ** $p < 0:05$, *** $p < 0.01$.

Table 8: Effect of Rain on Worries, entire sample

	(1) Worries	(2) Worries	(3) Worries	(4) Worries
Rain (t-1) x Farmer	-0.00466	-0.00579*	-0.00828*	-0.00832*
	(0.00288)	(0.00338)	(0.00428)	(0.00433)
Rain (t-1)	0.000580	0.000218	0.000370	-0.000907
	(0.000686)	(0.000884)	(0.000915)	(0.00148)
Farmer	2.015***	2.869***	2.893***	2.909***
	(0.0482)	(0.195)	(0.196)	(0.192)
Planting season				-0.123*
				(0.0647)
Rain (t-1) x Planting season				0.00119
				(0.00193)
Rain (t-1) x Female x Farmer			0.00738	0.00699
			(0.00573)	(0.00560)
Rain (t-1) x Farmer x Planting season				-0.00118
				(0.0161)
Female			0.0564	0.0575
			(0.0545)	(0.0545)
Rain (t-1) x Female			-0.000898	-0.000910
			(0.00234)	(0.00235)
Constant	-0.514***	-0.372*	-0.221	-0.136
	(0.0180)	(0.193)	(0.244)	(0.248)
Cortisol controls	No	Yes	Yes	Yes
Location FE	No	Yes	Yes	Yes
Month FE	No	Yes	Yes	Yes
N	1206	1201		1201

Effect of rain in past dekad (t-1) on worries in Nairobi and Kianyaga.
Cortisol controls include dummies for recent eating, smoking, drinking coffee or tea, performing intense physical activity, taking medication, or chewing miraa earlier on the same day. Location and month fixed effects control for grid within the rainfall data and month of the year, respectively. Robust standard errors in parentheses.
* $p < 0.10$, ** $p < 0{:}05$, *** $p < 0.01$.

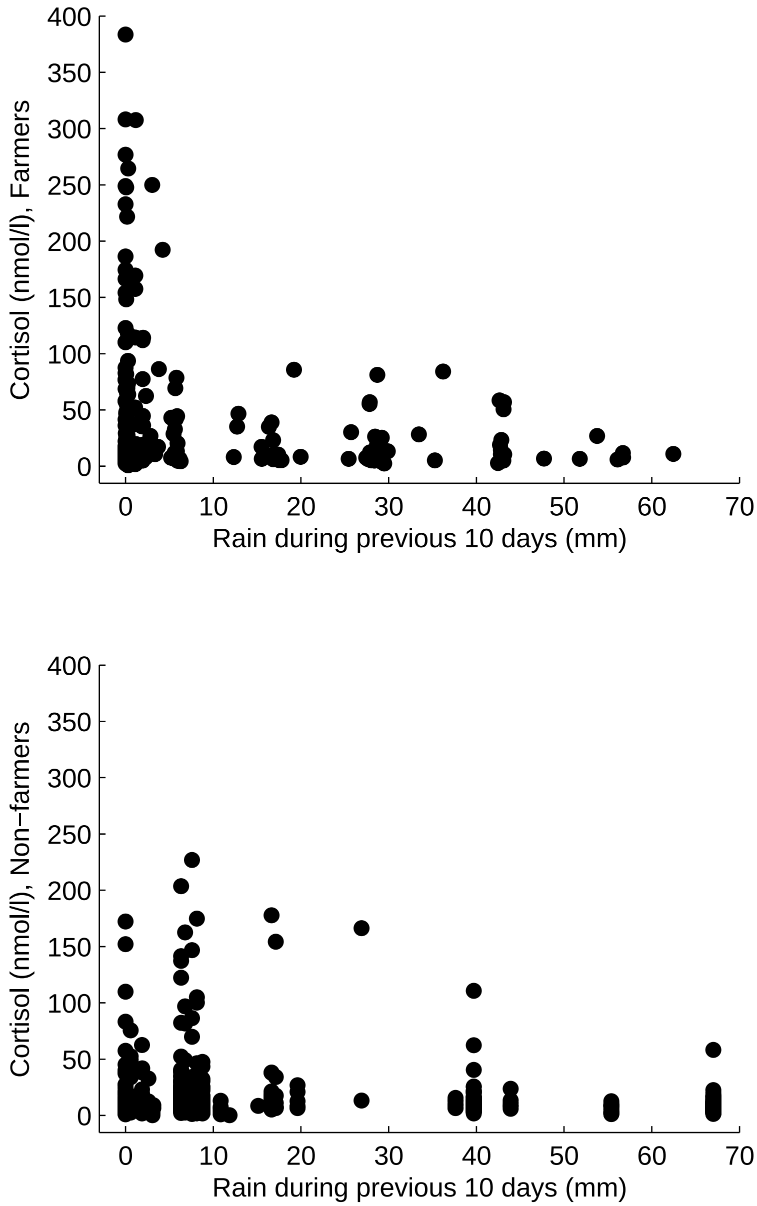

Figure 1: Relationship bewteen cortisol and rainfall. Rainfall is a household-specific variable denoting cummulate rainfall over the 10 days preceding the interview and cortisol sample. Cortisol is the average of two saliva samples obtained before and after the interview. The top panel shows data for farmers, the bottom panel for non-farmers.

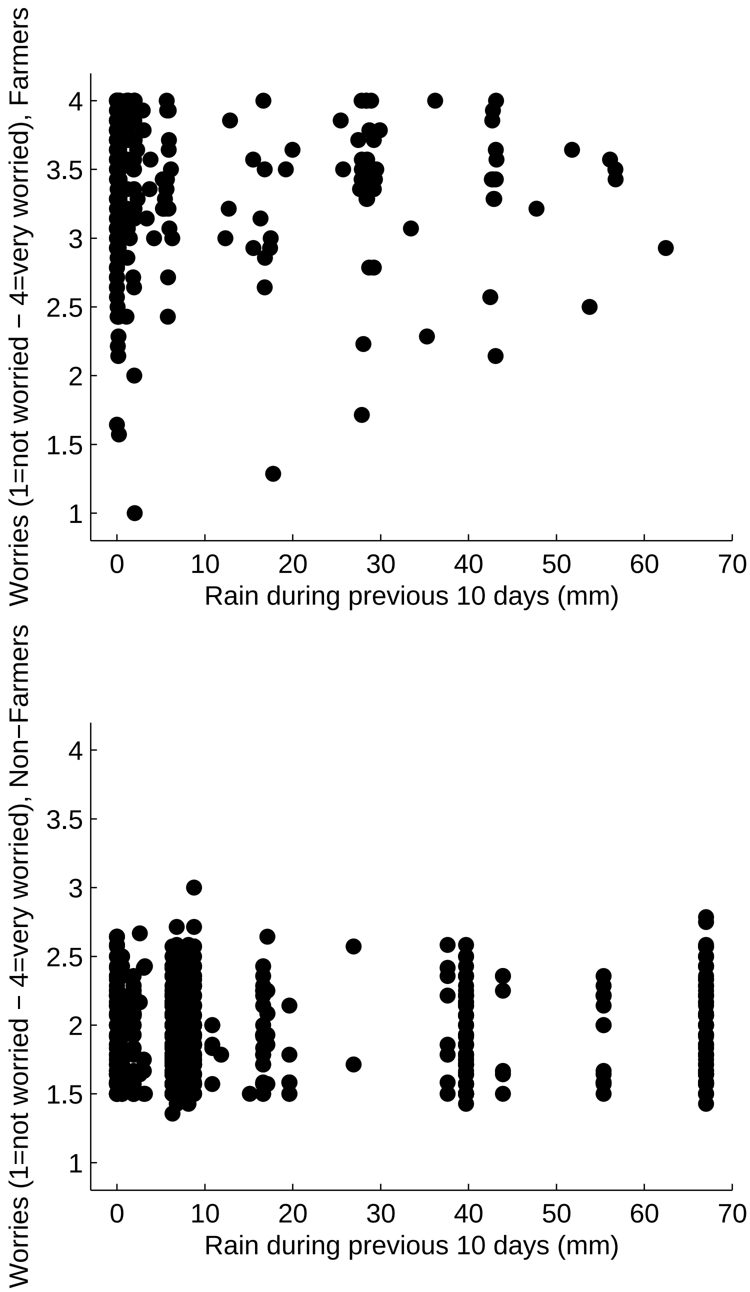

Figure 2: Relationship bewteen cortisol and worries about life. The worries variable is the average of 14 questions asking respondents how worries they are about different areas of their life, on a scale from 1 (not worried) to 4 (very worried). Cortisol is the average of two saliva samples obtained before and after the interview. The top panel shows data for farmers, the bottom panel for non-farmers.