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Does Fertilizer Use Respond to Rainfall Variability? Panel Data Evidence from Ethiopia

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Abstract

In this paper we use farmers' actual experiences with changes in rainfall levels and their responses to these changes to assess if patterns of fertilizer use are responsive to changes in rainfall patterns. Using plot and farm level panel data from the central Highlands of Ethiopia matched with corresponding village level rainfall data; results show that both the current year's decision to adopt and the intensity of fertilizer adoption is positively associated with higher rainfall levels experienced in the previous year. Furthermore, we find a concave relationship between previous season rainfall levels and fertilizer adoption, indicating that too much rainfall discourages adoption. Abundant rainfall in the previous year could depict relaxed liquidity constraints and increased affordability of fertilizer, which makes rainfall availability critical in severely credit constrained environments. In light of similar existing literature, the major contribution of the study is its use of plot level panel data, which permits us to investigate the importance of plot characteristics in fertilizer adoption decisions.

Key words: Fertiliser adoption; Rainfall; Highlands of Ethiopia; Panel data

JEL Classification: O12; O33; Q12; Q16; Q54.

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1. Introduction

Agriculture is inherently risky. Agroclimatic situations condition the performance of agricultural activities and determine the type of crops grown and animals reared (Downing, 1996; Watson et al., 1996; Reilly 1995; Smit et al. 1996; Risbey et al. 1999) and increased inter-annual climate variability accompanying mean climate changes has been argued to have a greater effect on crop yields than mean climate changes alone (Mearns et al., 1995).

However, in addition to conditioning production outcomes, uncertainty associated with climate variability may also affect investment decisions with upfront cost and uncertain outcomes. The use of productivity-enhancing external inputs is one such investment. In settings where financial and insurance markets are imperfect, households cannot freely borrow to finance external input use nor can they trade away the risk of crop failure in the insurance market. As Paxson (1992) finds, rainfall is positively correlated to income and rainfall variability -being one aspect of climate variability- negatively affects households' propensity to save. Hence, the decision to apply external inputs like fertilizer tends to be associated with climate variability.

A number of studies have documented the limiting role of resource and credit constraints on the use of modern agricultural inputs like fertilizer. In their study of the constraints with regards to use of inorganic and organic fertilizers by smallholder farmers in South Africa, Odhiambo and Magandini (2008) find that inability to access credit significantly limits fertilizer use. Similarly, in Madagascar, adoption of a high yielding rice variety-fertilizer package is shown to be hampered by liquidity constraints (Moser and Barrett, 2005).

In addition to financial constraints which impose ex-ante barriers to fertilizer use, missing formal insurance markets in developing countries imply that farmers face serious constraints in coping with production risks (Murdoch, 1995; Dercon, 2002). Indeed, covariate shocks due to climate change and variability e.g. droughts have long-lasting negative effects on households' welfare (Dercon, 2004). This implies that households have to rely on their limited resources to cope with such risks by reducing their vulnerability to such risks. Such risk avoidance strategies have been attributed to limited fertiliser use in developing countries (Lamb, 2003). This paper contributes to the limited empirical literature that assesses empirically the role of rainfall on farmers' factor demands. It does this by assessing the possible links between rainfall patterns and corresponding farmers' decisions to use fertilizer. As noted earlier, higher rainfall levels

are expected to result in increased harvests which in turn are expected to ease the liquidity constraints facing households. Relaxation of liquidity constraints could then mean that households are more likely to adopt fertilizers.

The analysis is based on three rounds of representative plot- and farm-level data from the Ethiopian Highlands. By focusing on plot-level analysis, our paper builds on Dercon and Christiaensen (2007) whose analysis was based only on farm-level analysis. We employ random effects estimators which allow us to treat each plot observation within a given household as a variable unit thereby controlling for intra-group correlation due to unobserved cluster effects in addition to unobserved effects. Our results confirm both at plot- and farm-level, that fertilizer adoption by farmers is positively associated with rainfall levels in the previous year, supporting the hypothesis that rainfall encourages fertilizer adoption by relaxing liquidity constraints. This is also in line with Seo and Mendelsohn (2008) and Bezabih et al. (2008) who find that the riskiness of crop portfolio over time is influenced by the rainfall patterns, as higher rainfall leads to higher harvests, increases liquidity and enhances risk bearing capacity.

The strength of the analysis therefore is that it is not based on implicit production risk. It deals with actual farmers' experiences with changes in rainfall levels, and their responses to these changes relative to other factors which influence their decision to apply fertilisers. Inclusion of such adaptive responses is critical to a valid assessment of the impacts of climate change and variability, given that such responses result in less or more adverse effects than if they are excluded.

The rest of the paper is organized as follows: section 2 presents the conceptual framework underlying the analysis while in section 3 we present the econometric framework that forms the basis of the empirical approach used in the paper. The data used in the analysis is discussed in section 4 together with a background on fertilizer use in Ethiopia. Section 5 presents and discusses the results of the econometric estimation and section 6 concludes the paper with policy implications.

2. The conceptual Framework

Rural farming households in developing countries operate under uncertain production environments with imperfect credit and insurance markets implying that liquidity constraints are a huge limiting factor in technology adoption decisions such as fertilizer adoption decisions. The rationale behind our conceptual framework is that fertilizer is a

risky input and is liquidity dependent. It argues that rainfall and in particular, lagged average rainfall, determines the level of output in the lag year and thus gives an indication of the degree of liquidity constraints faced by the household in the current year. Since fertilizer use is determined both by the level of liquidity constraints and the degree of uncertainty in the production environment, it responds directly to the lagged average rainfall. The conceptual framework we pursue is an adaptation of an agricultural household model by Shively (1997), which uses an expected utility maximization framework to represent investment decisions made under uncertainty.

Consider an agricultural household, which is assumed to maximize its expected returns from farming, i.e.:

$$\text{Max } E \left[\sum_{t=0}^T \beta^t \pi_t(d(\pi_{t-1})) \right], \quad (1)$$

subject to the farm income defined as:

$$\pi_t = A \left[f(d(\pi_{t-1}), x(\pi_{t-1}), \zeta) - c(d(\pi_{t-1}), x(\pi_{t-1})) \right] + wL + I, \quad (2)$$

and a household-specific safety-first constraint:

$$\Pr(\pi_t < \bar{I}) \leq \alpha \quad \forall t. \quad (3)$$

In equation (1), β is a per-period discount factor; π_t per-period net farm income, and $d = \{0,1\}$ denotes the decision to adopt fertilizer. The net farm income in the previous period is denoted by (π_{t-1}) and this is expected to be an indicator of the disposable income available to the household to spend on farm inputs. In equation (2), A denotes plot sized: $f(d(\pi_{t-1}), x(\pi_{t-1}), \zeta)$ is a stochastic production function that depends on the decision to adopt fertilizers (θ), other inputs (x), and a stochastic shock (ζ); and $c(d(\pi_{t-1}), x(\pi_{t-1}))$ is a cost function for inputs. Non crop incomes of the agricultural household are captured in equation (2) and are combination of nonwage income (I) and labor (L) supplied at the wage rate (w). \bar{I} is a threshold or critical level of income and α denotes a maximum allowable probability of falling below the threshold in equation (3).

The agricultural household should evaluate expected returns in terms of a probability distribution for minimum income and that is why the safety-first constraint is introduced in the household's problem. According to Shively (1997) this distribution will depend on the income-earning capacity of the household. Although restrictions could be used to

specify a closed form for the conditional probability distribution of returns, a more general approach is to re-express the safety-first constraint as:

$$\pi_t(D(\pi_{t-1})) + F^{-1}(\alpha)\sigma_\pi \geq \bar{I} \quad \forall t \quad (3')$$

where $F^{-1}(\alpha)\sigma_\pi$ is the inverse of the distribution function of returns and σ_π is a measure of spread (Boussard, 1979 cited in Shively, 1997).

The first order conditions for maximizing equation (1) subject to the constraints equations (2) and (3') leads to an optimum where in each period

$$\frac{\partial f}{\partial D} = \frac{\partial c}{\partial D} + \frac{\lambda}{(A-\lambda)} \frac{\partial F^{-1}}{\partial D} \quad (4)$$

where λ is the Langrangean multiplier associated with relaxing the safety constraint. Equation 4 above shows the marginal benefit-marginal cost condition for adoption that explicitly accounts for the cost of adoption in terms of its impact on the safety-first constraint in each period. If this constraint is binding, (i.e., if $\lambda > 0$), adoption decision will not be based solely on a comparison of net benefit flows between techniques, but will also depend on farm size, non-farm income, and the impact of adoption on the probability of income shortfall. Inverting equation (4) results in a demand function for fertilizer use of the form:

$$D = \phi(A, \pi_{t-1}, c, E\{F^{-1}(\alpha)\sigma_\pi | A, w, L, I\}). \quad (5)$$

In this paper we draw on the established link between rainfall and the household's farm income and the ability to save (Paxson, 1992; Hoddinott, 2006) to posit that rainfall variability impacts the safety-first constraint in equation (3') through the crop income in the previous period π_{t-1} , which is intuitively expected to affect the affordability of fertilizer use by households. Thus the equation the reduced form demand function for fertilizer use becomes:

$$D = \phi(A, W_{t-1}, c, E\{F^{-1}(\alpha)\sigma_\pi | A, w, L, I\}), \quad (5')$$

where W_{t-1} denotes the rainfall levels in period $(t-1)$. According to equation (5'), the decision regarding fertilizer use will depend on rainfall levels in the pervious period, plot size, the cost of inputs, and the shape of the expected probability distribution associated with the safety-first constraint. The probability distribution is conditioned on the income-earning capacity of the household. Furthermore, by influencing technology performance or adoption cost, farm or plot-specific attributes such as land quality or slope, socioeconomic characteristics may also influence adoption decisions. Including

the safety-first constraint in the adoption problem underscores the point that when technology adoption is costly, it has the potential to push a low-income household below its disaster level. As a result, one might expect that adoption decisions will be influenced by the productive capacity of the household. We can thus use equation (5') as a basis for the reduced-form empirical model to be investigated in the following section.

3. The econometric framework and estimation strategy

In this section we set up an econometric framework for analyzing the link between fertilizer adoption decisions and rainfall patterns. First, we specify the relationships between whether or not to adopt fertilizer and determinants of fertilizer adoption, to investigate the existence of a significant impact of rainfall patterns on the decision to use fertilizer. We then investigate if the quantity of fertilizer applied on a given plot is attributable to changes in rainfall patterns by studying the relationships between plot level fertilizer use, and yearly average rainfall.

The premise behind our hypothesis and the specification of the empirical model is that fertilizer is a risky input and is liquidity dependent. Our key decision variable - lagged average rainfall - by determining the level of output in the lag year- gives an indication of the degree of liquidity constraints faced by the household in the current year. Since fertilizer use is determined both by the level of liquidity constraints and the degree of uncertainty in the production environment, it responds directly to the lagged average rainfall. The advantage of using lagged rainfall here is that it is exogenous to current choices and as such provides a good proxy for income and consequently the ability of the household to afford fertilizer adoption.

Following the conceptual framework outlined in the preceding section as well as previous technology adoption literature (e.g. Dercon and Christiaensen, 2007), our empirical investigation is based on the following specifications of household h 's fertilizer adoption decisions:

$$d_{pt} = g(Z_{pt}, W_{p(t-1)}, \varepsilon_{pt}), \quad (6)$$

where d_{pt} is the decision by household h to fertilize plot p at time t ; $W_{p(t-1)}$ is the average yearly precipitation at time $(t-1)$ and Z_{pt} is a vector of other factors derived

from economic theory and earlier work on fertilizer adoption. These include characteristics such as plot-specific attributes which may influence adoption decisions by influencing technology performance or adoption costs. When market imperfections are important, inclusion of household characteristics and resource endowments in explaining investment decision is important (Pender and Kerr, 1998; Holden et al., 2001), in addition to other determinants of investment decision. Accordingly we include variables to capture the “natural capital” of the plot (biophysical characteristics such as soil fertility, slope and soil type); the household’s endowments of physical capital (land, livestock); the human capital (education, age, and gender of household head, number of female and male adults in the household); and random factors are captured by ε_{pt} .

As the next section describes, not all surveyed plots (and households) were fertilized. Given our conceptual framework which considers the decision to adopt fertilizer as a binary decision, our econometric strategy is to estimate two models: the first model estimates the decision to adopt (a binary decision) and the second model is a censored regression model which is used to correct for the fact that not all surveyed parcels were fertilized. This allows for the possibility that the decision to adopt fertilizer and the intensity of adoption are determined by different factors. We chose this over selection models such as the Heckman model due to lack of strong theoretical arguments to guide the selection of exclusion variables that determine the decision to adopt fertilizer but not the intensity of adoption

Thus given a latent variable K_{pt}^* , that is observed only when fertilizer application takes place, the decision by household h to adopt fertilizer use on plot p at time t is such that:

$$\begin{aligned} K_{pt}^* &= \beta_0 + \beta_1 Z_{pt} + \beta_2 W_{p(t-1)} + \beta_3 W_{p(t-1)}^2 + \varepsilon_{pt} \\ d_{pt} &= 1 \text{ if } K_{pt}^* > 0 \\ &= 0 \text{ otherwise} \end{aligned} \quad , \quad (7)$$

where d_{pt} is a dummy that denotes the decision by household h to adopt fertilizer on plot p at time t . Thus the decision to adopt fertilizer is modelled as a binary choice model. The parameters to be estimated are $\beta_0, \beta_1, \beta_2$ and β_3 . It is assumed throughout the paper that the error term, ε , is such that (Z, ε) and $(W, \varepsilon) \square i.i.d$ and $N(0, \sigma^2)$. We include a quadratic term of lagged rainfall levels to allow for the possibility that there is

a threshold level of rainfall above which the marginal benefit associated with fertilizer application declines.

To use the random effects estimator we decompose the error term into two components such that

$$\varepsilon_{pt} = \varphi_p + \mu_{pt}, \quad (8)$$

where we also assume that $\mu_{pt} \square i.i.d$ and $N(0, \sigma^2)$. φ_p is assumed to be independent random draws from a normal distribution, where we assume $\varphi_p \square N(0, \sigma^2)$, as before. This treatment lends itself to a random effects estimator whereby we treat each plot observation within a given household as a variable unit. This means that in addition to controlling for unobserved effects we are also control for intra-household correlation due to unobserved cluster effects (Wooldridge, 2002) such as features of microclimates. Thus in accordance with the foregoing discussion, our estimation of the decision to adopt fertilizer on a given plot, applies the panel-data random effects estimator model with the dependent variable being observed across three time periods, and the weather variable is observed with lagged time.

Given that not all plots were fertilized, estimating the intensity of fertilizer requires the use of econometric models that correct for this censoring of the dependent variable, since the use of Ordinary Least Squares (OLS) on the whole sample will give inconsistent estimates (Wooldridge, 2002). Accordingly a censored regression model is used. Specifically we estimate a random effects Tobit model on the intensity of fertilizer use. A censored regression model is such that:

$$\begin{aligned} K_{pt}^* &= \beta_0 + \beta_1 Z_{pt} + \beta_2 W_{p(t-1)} + \beta_3 W_{p(t-1)}^2 + \varepsilon_{pt} \\ K_{pt} &= K_{pt}^* \text{ if } K_{pt}^* > 0 \\ &= 0 \text{ otherwise} \\ \Rightarrow K_{pt} &= \max(0, \beta_0 + \beta_1 Z_{pt} + \beta_2 W_{p(t-1)} + \beta_3 W_{p(t-1)}^2 + \varepsilon_{pt}) \end{aligned}, \quad (9)$$

where K_{pt} is the observed intensity of fertilizer application i.e. the amount of fertilizer used per hectare, in kilograms. Assuming the error term is independently, identically and normally distributed with zero mean and constant variance leads to a Tobit model, originally developed by Tobin (1958). Decomposing the error term according to equation (8) makes it possible for us to estimate a random effects Tobit model thus allowing us to control for intra-group correlation due to unobserved cluster effects in addition to unobserved effects.

4. The data and fertilizer use in Ethiopia

The data

To estimate the models we use plot-level panel data from the Highlands of Ethiopia. The dataset contains rich information on plot and farm characteristics, cropping patterns, the traditional and modern inputs used in each period, as well as socioeconomic characteristics of a total of 1500 rural households. The data were collected from rural households in two districts of the Amhara National Regional State by the Environmental Economic Policy Forum for Ethiopia and Addis Ababa University, Department of Economics. The regional state comprises part of the northern and central Highlands of Ethiopia. The data collection was done in three waves which covered the years 2002, 2004 and 2007. Given little intra- and inter-village migration, not much attrition is experienced in forming the panel. In the few cases where respondents are missing in the succeeding waves of the survey, the households were dropped out of the sample. We match this data set with longitudinal annual rainfall data collected from local stations by the Ethiopian Metrology Authority. Monthly rainfall data was collected from four meteorological stations close to the twelve study sites. These monthly figures are then used to compute the annual figures, which we use in this analysis.

Summary statistics of all the variables used in the ensuing analysis are presented in Table 1 below. Our variable of interest is *Lagged rainfall* which increases productivity in the previous year, thereby easing liquidity constraints faced by households in adoption decisions. Though difficult to verify given data limitations, *Lagged rainfall* could be correlated with the levels of rainfall households anticipate in the current year which could intuitively influence their fertilizer adoption decisions, with higher anticipated rainfall levels encouraging adoption of fertilizer since use of fertilizers in dry years will burn seeds and thus increase the risk of low harvests. The average *Lagged rainfall* over the period of analysis is around 1205mm while the intensity of plot-level fertilizer use is 156kg and 65kg at farm-level. The mean plot size is approximately 0.22ha while the mean farm-size is 1.04ha. Around 87% of the households are male-headed. The number of times the household has experienced land changes by the government; *Frequency of land change*, is considered an indicator of tenure security.

Table 1: Definition of variables and descriptive statistics

Variable	Description	Mean	Std. Error
<i>Fertilizer Use</i>			
Plot-level adoption	Whether any fertilizer was applied on the plot (1=yes, 0=no)	0.20	0.40
Plot-level intensity	Fertilizer application per hectare, in kilograms	155.82	7369.8
Farm-level adoption	Whether any fertilizer was applied on the farm (1=yes, 0=no)	0.40	0.49
Farm-level intensity	Fertilizer application per hectare, in kilograms	65.14	759.0
<i>Rainfall</i>			
Lagged rainfall	Lagged rainfall levels/1000, in mm	1.205	0.223
<i>Socioeconomic characteristics</i>			
Gender	Gender of household head (1=male, 0=female)	0.87	0.34
Age	Age of household head	48.73	15.34
Education	Level of education of household head	1.92	0.96
Formal farmer training	Household head received some formal farmer training (1=yes, 0=no)	0.17	0.37
Male adults	Number of male adults in the household	3.03	1.65
Female adults	Number of female adults in the household	2.79	1.40
Oxen	Number of oxen owned and used by the household	2.12	27.53
Frequency of land change	Frequency of land change	0.71	1.06
<i>Plot and farm characteristics</i>			
Plot distance	Distance from homestead to the plot, in minutes	14.53	21.46
Plot size	Size of the plot, in hectares	0.23	0.24
Average distance	Average distance from homestead to each plot, in minutes	1.49	16.86
Farm size	Size of the farm, in hectares	1.04	0.90
Fertile	Proportion of plot that is perceived as fertile	0.41	0.37
Moderately fertile	Proportion of plot that is perceived as moderately fertile	0.39	0.35
Flat slope	Proportion of plot that is of flat slope	0.67	0.33
Moderate slope	Proportion of plot that is of moderate slope	0.28	0.31

Source: Authors' own calculation.

Inorganic fertilizer use in Ethiopia

According to FAO (1995) fertilizer was first introduced to Ethiopia in 1967 following four years of trial carried out by the Imperial Government with the assistance of FAO. Fertilizer adoption by the peasant sector, which was 14,000 metric tons in the year 1974/75, reached about 50,000 metric tons in 1979/80 and 200,000 metric tons in 1993/1994. About 80 percent of the fertilizer used is for cereals and 45 to 50 percent of it is applied on the major staple, teff where as the remaining on wheat, barley, maize and sorghum. Only about one-third of the farmers in highlands apply fertilizer and their rate of application is much lower than 50kg/ha on average (FAO, 1995). Demeke et al. (1998) documented that it is recommended to use 200 kg (100kg Urea and 100 kg Di-Ammonium phosphate (DAP)) per ha for all cereal crops in most areas of Ethiopia. The current intensity of fertilizer use is therefore quite lower than recommended. Table 2

gives a year-by-year breakdown of fertilizer adoption and intensity of use in the sample we analyze.

Table 2: Fertilizer use in the Highlands of Ethiopia, 2002-2007

Year	Farmers using fertilizer (%)		Application rate per ha (kg)	
	Plot-Level	Farm-Level	Plot-level	Farm-Level
2002	23.68	53.05	42.092	35.123
2004	18.46	36.65	51.3889	69.269
2007	17.45	30.57	348.7999	89.769

Source: Authors' own calculation.

Table 2 indicates that approximately 53 percent of the farmers in the sample areas applied fertilizer on their farms in the year 2002. This figure declined to about 37 and 31 percent in the years 2004 and 2007. Consistent with all the previous studies, table 2 also shows that intensity of fertilizer use is still very low in the Highlands of Ethiopia. In the year 2000, an average of about 35 kg fertilizer was applied per ha and this figure increased to 69 and 89 kg per ha in the years 2004 and 2007. Although the number of farmers adopting fertilizer is declining, intensity among farmers choosing to use fertilizer has been improving. However, the intensity of fertilizer use is still lower than the recommended rate of 200 kg per ha. Dercon and Christiaensen (2007) also documented that both adoption rates and intensity of fertilizer use are relatively low; with only 22 percent of all households in the sample using fertilizer in each period and only about 30 kg per ha being used, far below the recommended application rate of 200 kg per ha. Thus the main objective of the study is to examine factors explaining this low adoption rates and subsequent intensity of adoption, with a focus on how rainfall impacts adoption decisions.

With the exception of Dercon and Christiaensen (2007), studies examining factors determining fertilizer adoption decisions of farmers in rural Ethiopia have tended to ignore risk factors associated with rainfall variability, probably due to data unavailability. Accordingly the main contribution of this paper lies in employing plot-level panel data collected from about 1,500 rural households in the Highlands of Ethiopia to investigate whether households, faced with imperfect insurance and credit markets, use risk avoidance as a strategy to cope with threats to harvests (which is directly related to income) due to climate change and variability. The main improvement to Dercon and Christiaensen (2007) is our use of both plot- and farm level

data whereas their analysis is based only on farm-level data. This way we are able to investigate the significance of plot characteristics in fertilizer adoption decisions.

5. Empirical results and discussion

Table 3 below presents the random effects Probit results for the decision to adopt fertilizer and random effects Tobit results for the intensity of adoption, both at plot-level. The coefficient ρ basically represents the proportion of the observed total variance of the error term due to random effects. Thus the test for the null hypothesis that $\rho=0$ is rejected justifying the use of a random effects estimator. This demonstrates the importance of intra-household correlation due to unobserved cluster effects in fertilizer adoption decisions.

We also estimate both the random effects Probit and Tobit at farm-level. However, since this analysis focuses mainly on plot-level analysis we report the results from the farm-level analysis in Table A1 in the appendix. The results have similar implications to plot-level results presented and discussed here.

Table 3: Random Effects Probit and Tobit on Plot-Level Fertilizer Adoption

Variable	Random Effects Probit		Random EffectsTobit	
	Coeff.	Std. Error	Coeff.	Std. Error
<i>Rainfall</i>				
Lagged rainfall	9.739***	2.576	45.390***	12.155
Lagged rainfall squared	-0.004***	0.001	-0.018***	0.005
<i>Socioeconomic characteristics</i>				
Gender	0.476***	0.167	2.374***	0.792
Age	-0.012***	0.004	-0.060***	0.017
Education	0.017	0.053	0.020	0.253
Formal farmer training	-0.183	0.119	-0.913	0.565
Male adults	0.002	0.033	0.009	0.158
Female adults	-0.089**	0.036	-0.458***	0.174
Oxen	0.203***	0.054	0.969***	0.252
Farm size	0.124**	0.061	0.633**	0.260
Frequency of land change	-0.112	0.084	-0.491	0.390
<i>Plot characteristics</i>				
Plot distance	0.000	0.002	0.003	0.008
Plot size	0.283*	0.145		
Fertile	-0.579***	0.165	-2.800***	0.773
Moderately fertile	-0.580***	0.161	-2.809***	0.752
Flat slope	-1.129***	0.239	-5.810***	1.127
Moderate slope	-0.613**	0.253	-3.379***	1.182
Constant	-6.141***	1.590	-27.237***	7.472
Rho	0.472	0.037	0.458	0.034
LR test of Rho=0: p-value		0.000		
Wald chi2		126.73		120.28
Log-likelihood		-1494.508		-3147.713
Observations		3648		3646
Number of household id		914		914

Note: * significant at 10%; ** significant at 5%; *** significant at 1%

Climate variability and fertilizer adoption

The primary objective of this paper has been to analyze the link between rainfall levels and farmers' fertilizer adoption decisions, our hypothesis being that higher previous season rainfall levels will lead to increased fertilizer adoption. This is because abundant rainfall in the previous year translates into good harvests which could in turn relax liquidity constraints and consequently lead to increased probability of applying fertilizer as well as the intensity of fertilizer application. Our results suggest that both the decision to adopt fertilizer and the intensity of adoption in a given year is positively affected by previous year's rainfall levels, in line with *a priori* hypothesis. Furthermore we find a concave relationship between previous season rainfall levels and fertilizer

adoption. This suggests for a threshold level of rainfall after which the marginal impact of rainfall on fertilizer use starts to decline. This result is also confirmed at farm-level (see Table A1 in the appendix) indicating that even at the farm level both the decision to adopt fertilizers and the intensity of adoption in a given year is positively affected by previous year's rainfall levels.

This result demonstrates the poverty implication of climate variability and change. Climate variability and change, via its direct impact on crop income, is expected to worsen poverty levels by lowering incomes of better off farmers while those who are already poor will remain trapped in poverty as adverse weather patterns will negatively impact on their income prospects. The link between rainfall levels and crop or farm income is well established (Hoddinott, 2006). Furthermore, rainfall variability negatively affects households' propensity to save (Paxson, 1992). Moreover, existing literature has established that poverty, being an indicator of vulnerability due to its direct association with income or access to resources, significantly constraints households in coping with impacts of extreme weather changes (Adger, 1999). This informs policies that seek to mitigate or adapt to climate variability and change to explicitly factor in the impact of poverty on the ability to cope with such changes. A plausible policy is to provide credit and insurance in as far as its provision might ease the constraints households face when they try to invest in farm inputs. One possibility is to develop index-based crop insurance schemes whereby indemnity payments are made when an agreed upon condition, in this case when recorded rainfall at a particular station falls below a certain threshold. The advantage with such insurance schemes is that they are based on conditions that are independent from both farmers and insurers' influence thereby minimizing moral hazard and adverse selection problems. Such mechanisms might ease the households' vulnerability to crop failure which might constraint the ability to invest in farm inputs.

Another possible explanation to our finding is that anticipated weather changes are informed by current weather patterns i.e. anticipation about next year's rainfall patterns are influenced by current year rainfall patterns⁵. Thus given the anticipated rainfall patterns, households use opportunities within their means to shield themselves against

⁵ Anecdotal evidence shows that farmers anticipate bad weather once in four years. The survey years and the rainfall observation years all correspond to the 'good weather' years according to this anecdotal evidence. Hence, farmers in the study area may have expectations that current rainfall is close to previous rainfall in pattern.

crop failure; in this case they either abandon or reduce fertilizer use given that they anticipate lower rainfall levels, in line with Fufa and Hassan (2006). Higher anticipated rainfall levels signal reduced anticipated risk of fertilizer use, since applying fertilizers under dry conditions could simply burn seeds and increase the probability of crop failure. In this way reducing fertilizer application can serve as a relevant strategy in coping with production risks associated with climate variability, with the expectation being that higher rainfall levels will be associated with increased adoption of fertilizers and vice versa. This is also supported by findings by Smit et al. (1996) and Hucq et al. (2000) who find evidence that farmers alter the intensity of input use to reduce the risks associated with climate change.

Other correlates of fertilizer adoption

Existence of gender differences in technology adoption is confirmed, with male-headed households being more likely to adopt fertilisers. This lends support to the contention that women are generally discriminated against in terms of access to productive inputs (Dey, 1981; Doss, 1999). Given the demonstrated contribution of fertilisers to raising agricultural yields and land productivity in sub-Saharan Africa (Mwangi, 1997) and particularly in Ethiopia where the population growth rate and land degradation places a challenge on agriculture (Fufa and Hassan, 2006), such discrimination with regards to productivity-enhancing farm inputs can result in gender differentials in farm productivity (Udry et al., 1995) and subsequently poverty. This is further supported by the fact that female labor, proxied by the number of female adults in the household, is associated with lower probability and intensity of adoption. The negative impact of female labor might also be reflecting households' preference for female labor-saving technologies particularly where there are alternative opportunities for female labor.

The probability of fertilizer adoption and intensity of adoption decreases with age, consistent with Fufa and Hassan (2006) and Chianu and Tsujii (2004). This suggests that older household heads might have a shorter planning horizon and thus less likely to adopt soil conservation practices than younger household heads. Furthermore research has found evidence that younger farmers are more likely to adopt technologies and given that they have more energy, they are more likely to invest in productivity-enhancing technologies (Alavalapati et al., 1995).

The suggested positive impact of oxen ownership on both the decision to adopt as well as the intensity of adoption suggests that wealthier households have an advantage

in adoption of fertiliser. The number of oxen owned by a household can be taken as a proxy for household wealth (Clay, et al., 1998). Wealthier households are better placed to purchase fertilisers as well as to amass additional resources that can be used for on-farm investments. Poverty has been found to be a major constraint in African agriculture (World Bank, 2007). The significance of oxen in determining use of farm inputs such as inorganic fertilisers combined with the finding that fertiliser enhances productivity in Africa (Mwangi, 1997) confirms this. This suggests that policies aimed at alleviating poverty will help alleviate constraints to access and use of farm inputs needed to improve agricultural productivity.

With regards to plot characteristics, the positive impact of plot size could be suggesting that it might not be economically efficient for farmers with small farm holdings to apply fertilisers due to economies of scale effects at plot-level, for example, packaging of fertilisers. Similarly the positive impact of farm size (Table A1 in the appendix) suggests that larger farmers benefit from either economies of scale or preferential access to inputs and credit (Polson and Spencer, 1991) and/or might be able and willing to bear more risks than small farmers. It could also be the case that farm size is capturing the wealth status of the household in which case this is in line with concerns we raised earlier regarding the constraints poverty imposes on fertiliser adoption.

Farmers have been found to have fairly good indigenous knowledge of the challenges facing their farming systems and their assessment of soil quality impacts greatly on their soil fertility management strategies (Edwards, 1987 cited in Adesina, 1996). Given that the primary goal of fertilizer use is to enhance soil fertility by supplying the nutrients necessary for improved crop yields (Mwangi, 1997), it is intuitive that perceived soil fertility is associated with reduced adoption and subsequent intensity of adoption. Gentle or flat slopes are associated with less erosion compared to moderate slopes (Ovuka and Ekbom, 1999) implying that they experience less nutrient loss and thus farmers might not see the need to apply fertilizers on them. Thus intuitively we find that the likelihood of adoption as well as adoption levels decline in the proportion of the plot that is both flat and moderately sloped i.e. the flatter the plot, the less likely the adoption.

6. Conclusions and policy implications

This paper investigates how farmers' adoption of fertiliser is influenced by changes in precipitation, using plot and farm level panel data from the central Highlands of Ethiopia matched with corresponding village level rainfall data. The analysis is an addition to the limited empirical literature that assesses empirically the risk factors associated with rainfall variability and how this impacts investments in productive farm inputs such as fertilizer. Our main hypothesis is that higher anticipated rainfall levels will lead to higher fertilizer adoption. This is based on the argument that higher anticipated rainfall is also to result in increased harvest levels which in turn are expected to ease the liquidity constraints faced by households. The major contribution of the analysis lies in its use of plot level panel data that highlights the importance of not only household-level but also plot level characteristics. In addition, the strength of the analysis is that it is based on actual weather changes and explicitly examines farmers' responses to these, which conventionally is assumed in climate assessment studies.

The results indicate that in a world of credit and insurance market imperfections, previous year rainfall levels relaxes constraints due to such imperfections by increasing households disposable income. Thus our results suggest for possible poverty traps on poor farmers in the face of uninsured risks due to climate change and variability, given that rainfall variability is one aspect of climate change and variability. Given the link we establish between rainfall and fertiliser adoption patterns, climate change and variability, via its direct impact on crop income, is expected to worsen poverty levels by lowering incomes of better off farmers while those who are already poor will remain trapped in poverty as adverse weather patterns will negatively impact on their income prospects. This is evidence that there may be a market for weather-based derivatives in low-income agriculture and that the next step would be to establish the value of such insurance and the proper mechanism design. Provision of such insurance might ease the constraints households face when they try to invest in farm inputs. Furthermore, such mechanisms need to be accompanied by policies that seek to eliminate possible discrimination against female household heads in terms of access to productive inputs such as fertilisers. The significance of wealth indicators imply that policies aimed at poverty alleviation will help ease constraints farmers face in technology adoption.

The analysis is important in informing future studies that attempt to assess the link between weather related uncertainty and agricultural investment in credit constrained

settings. The fact that we find evidence that households depend on good weather to make necessary productivity enhancing investments underlies the enormous importance attached to weather not only in determining current productivity but also future investments.

The analysis in this paper is based on average rainfall (abundance) and the impact of its variability on fertilizer use over years. Equally (even more) important measure in the Ethiopian context is the timing and variability of rainfall in a given year, which not only affects productivity, but also conditions fertilizer adoption decisions. Enhancing fertilizer use by Ethiopian farmers would require policy measures that provide insurance against losses associated with such variability. In addition, given the near-total dependence of the Ethiopian economy on such risk-prone, small-holder agriculture, short-term insurance measures might not be sustainable; and structural measures that reduce dependency on agriculture, particularly crop production, such livestock as off-farm employment options are worth exploring and investing in.

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Appendices

Table A1: Random Effects Probit and Tobit on Farm-Level Fertiliser Adoption

Variable	Random Effects Probit		Random Effects Tobit	
	Coeff.	Std. Error	Coeff.	Std. Error
<i>Rainfall</i>				
Lagged rainfall	21.742***	3.686	49.840***	8.412
Lagged rainfall squared	-0.008***	0.001	-0.019***	0.003
<i>Socioeconomic characteristics</i>				
Gender	0.736***	0.213	2.224***	0.522
Age	-0.018***	0.005	-0.047***	0.011
Education	-0.001	0.070	0.004	0.172
Formal farmer training	-0.076	0.157	-0.195	0.382
Male adults	0.005	0.041	0.031	0.105
Female adults	-0.105**	0.045	-0.266**	0.113
Oxen	0.261***	0.078	0.804***	0.181
Frequency of land change	-0.249**	0.126	-0.496*	0.290
<i>Farm characteristics</i>				
Average distance	-0.002	0.003	-0.001	0.009
Farm size	0.456***	0.081		
Fertile	-0.972***	0.230	-2.356***	0.533
Moderately fertile	-0.940***	0.219	-2.191***	0.519
Flat slope	-1.520***	0.346	-3.836***	0.786
Moderate slope	-0.796**	0.352	-2.014**	0.821
Constant	-12.443***	2.256	-27.076***	5.183
Rho	0.489	0.089	0.527	0.063
LR test of Rho=0: p-value		0.000		
Wald chi2		108.66		157.03
Log-likelihood		-641.076		-1601.627
Observations		1220		1215
Number of household id		936		932

Note: * significant at 10%; ** significant at 5%; *** significant at 1%