Flexible insurance for heterogeneous farmers: results from a small scale pilot in Ethiopia*

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Abstract

We analyze the effectiveness of a new approach in providing weather index based insurance products to low income populations. The approach is based on the concept of providing multiple weather securities that pay a fixed amount if the event written on the security (that monthly rainfall at a nearby weather station falls below a stated cut-off) comes true. The securities have three characteristics-simplicity, flexibility and inclusivity-that can encourage stronger take up rates than the ones observed for current weather index based insurance policies. A theoretical model is developed to outline the conditions in which weather securities could outperform crop-specific weather index based insurance policies. Data collected during both an experimental game and real purchases of such insurance policies among farmers in southern Ethiopia suggests that the securities are well-understood and can fit heterogeneous farmer needs. This paper documents: (i) understanding of securities among participants, (ii) transmission of information about weather securities among members of endogenously formed risk sharing groups, and (iii) the nature and manner of purchase decisions made.

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1 Introduction

Risk characterizes life for many of the world's poorest households. When this risk is uninsured it poses a considerable cost to current and future welfare as bad events cause reduced consumption and asset loss. Additionally, without insurance households take action to limit their exposure to risk-they may pass up a profitable opportunity that is considered too risky, diversify the types of economic activities pursued, or keep as many assets as possible in easily disposable forms-and as a result lower their average income (Eswaran and Kotwal, 1990; Morduch, 1991; Dercon, 1996; Fafchamps and Pender, 1997; Kurosaki and Fafchamps, 2002; Hill, 2009). Uninsured risks thus prevent many households from starting an asset accumulation process that allows them leave low income levels and poverty.

Financial instruments that allow households to manage risk improve farmers' welfare when bad events occur and help farmers use their resources in more efficient ways. For example, in Ethiopia, farmers more able to manage risk are found to be more likely to invest in fertilizer, even though it has a positive expected return for many households (Dercon and Christiaensen, 2007).

Weather index-based insurance products have made possible the provision of insurance against uncertain rainfall outcomes that affect the incomes of the rural poor. By basing payouts on an index rather than costly farm-level loss assessments, these products have made it possible to provide insurance to smallholder farmers. However demand for weather index-based products has been limited (Cole, Gine, Tobacman, Topalova, Townsend, and Vickery, 2009; Giné, Townsend, and Vickery, 2008; Giné and Yang, 2007) and many index-products have not progressed beyond the pilot stage. Further innovation is required before large-scale expansion of insurance markets for smallholder farmers is realized.

There are a number of reasons for the limited development of weather-index insurance markets, some of which are related to product design. Typically index-based products are complex (payouts are based on units that are hard to understand - a weighted measure of millimeters), only available for specific crops, susceptible to basis risk (which when combined with their complexity jeopardizes trust in the product) and tailored to compensate the losses of an average farmer which may be quite different from the losses of heterogeneous farmers each with different cultivation practices (Suri, 2006). Index-products have also remained expensive, perhaps as a result of limited economies of scale. As a result demand for index products has been quite low. On average about 10% of potential clients buy the products. These clients tend to purchase only a small amount of coverage and do not tend to be repeat buyers (Cole, Gine, Tobacman, Topalova, Townsend, and Vickery, 2009).

In this paper we test an approach based on the concept of providing multiple weather securities rather than one unique insurance policy. Weather securities are simple insurance policies that pay out a fixed amount if the specified event comes true. In this case, the events in question are monthly rainfall totals measures at a nearby weather station. The securities have three characteristics-simplicity, flexibility and inclusivity-that can encourage stronger take up rates than the ones observed for current weather index based insurance policies.

We undertook a real-time experimental game in southern Ethiopia to test the approach. The experimental game we conducted was like a laboratory experiment in that decisions were made with money endowed within the game, but decisions were made in real time and payouts were made on the basis of real events. Individuals were randomly selected to participate in the experiment. Participants were endowed with money at the beginning of the season and chose whether or not to purchase securities, that would pay out at the end of the season on the basis of the rainfall level experienced.

In the subsequent season a local insurance company offered these weather securities and real purchases were observed. Take-up was quite high, with take-up rates of 20% among informed farmers.

In this paper we document the concept behind the design of these securities, and assess the evidence for heterogenous rainfall needs in a small locale using a quantitative ranking of yearly rainfall by 240 households within one kebele (a collection of 4-5 villages). We then describe the pilot undertaken in more detail, and characterize understanding among participants. We analyze the purchase decisions made, and compare these findings to the purchase decisions made in the following season when weather securities were offered by a local insurance company. The evidence presented shows that that weather risks are not defined entirely by crop choice and that securities are well suited to fit the needs of farmers with heterogenous weather risks.

2 Weather securities

In this section we develop a two-period model in which we introduce the notion of weather securities. We show basic properties of the model and use it to motivate a discussion outlining how weather securities compare to standard index-based insurance products, and the conditions under which weather securities might provide better insurance services than a standard index-based insurance scheme.

There is wide consensus that the most promising approach to provide weather insurance to smallholders is one that is based on linking payouts to an independently observed index. Index-based schemes minimize ex-post verification costs, by ex-ante linking an index and the losses to be insured. Index-based insurance schemes also eliminate moral hazard and limit adverse selection problems. In recent years index-insurance has been sold for Haricot beans in Ethiopia (Nyala / WFP), groundnuts in India (Basix), groundnuts and tobacco in Malawi (World Bank / Microensure), rice in the Philippines (Microensure), cotton in Peru (La Positiva) among others (for a full list and details see Hess and Hazell (2009)).

Thus far, index insurance products have designed a payout schedule that links the index to the yields of a specific crop. These schedules have been defined using water-balance crop models to reduce the basis risk between farmers' losses and the index on which payouts are determined. The water-balance crop models and yield reduction coefficients that are available are somewhat limited for this task in that they have largely been modeled and tested in temperate climates for crops grown under ideal conditions (no nitrogen or phosphate deficiency) on large plots that are not intercropped (Allen, 1998; Hansen and Jones, 2000; Hansen, 2001). Through adaptation in focus group discussions the crop models can be carefully applied to a given area, but the underlying parameters are still from an environment quite different to the one indexed insurance products are usually designed for, and as a result there is a limit to the accuracy of their predictions. There are also some constraints imposed on the insurance by taking a crop model approach: the insurance can become more complex as the payout is often a weighted sum of rainfall deficit; the explicit link to crop yield can lead to basis risk being more hidden in marketing; it makes the contract inherently less flexible if farmers switch crops or varieties; and it segments the customer base when farmers in one area are growing many different crops.

One alternative is a generic weather-index insurance product designed to insure farmers against bad weather events rather than specific crop losses (as suggested in Skees, Hazell, and Miranda (1999), and Leftley (2009)). A recent example of such a product is the flood insurance offered by Munich Re in Indonesia in which farmers are paid on the basis of the level of water recorded at a given point in the river. In this paper we discuss the development and piloting of such products in the form of weather securities designed to insure farmers against different characteristics of drought. To the authors best knowledge this was the first time, such a system of securities has been designed and tested. Each security pays a fixed amount for a different aspect of weather risk (in this case the amount of rainfall at the local weather station in different months) and farmers build their own portfolio by buying securities for the rainfall risk they are most concerned about given the crops they grow and the production practices they use.

Weather securities have two important features that may make them potentially superior to standard index-based insurance. First, weather securities are easy to understand. Each security pays a fixed amount of money if a given state-contingent event occurs, and pays nothing otherwise. No further calculation is required to determine whether, or how much, the security will pay. In the context we consider the state-contingent event is defined based on the number of millimeters that fall at the local weather station. This can be contrasted with index-insurance in which the payout amount is determined based on a formula weighting the amount of rain that fell at different points of the season. Given low education levels among the target population, easy understanding seems to be a necessary condition, although not sufficient, for any successful insurance scheme. We explore levels of understanding among the experiment participants later in the paper.

Second, weather securities are flexible, and can thus accommodate different demands for contingent payoffs coming from heterogenous farmers. Farmer's rainfall requirements vary not only with crop, but also with variety, planting dates and timing of input application. These vary from farmer to farmer, and season to season, even within quite small geographical areas (Suri, 2006). The type and number of securities bought can be chosen by each farmer depending on their crop portfolio and production practices in a given year. This feature of our proposed approach represents a large conceptual difference to the standard unique policy approach in which a policy is designed according to the average rainfall requirements of one crop cultivated under certain practices in a given area. And there is a fixed structure of contingent payoffs. We will formalize this difference in the model below, and use survey data to quantify its importance for our experimental setting.[1]

It is worth noting that this feature of the weather securities is very important if provision of insurance has unanticipated impacts on farmer behaviour. Much research has suggested the purchase of insurance will result in behavioral change as households invest more in higher return but riskier activities (Eswaran and Kotwal, 1990; Morduch, 1991; Dercon, 1996; Fafchamps and Pender, 1997; Kurosaki and Fafchamps, 2002; Hill, 2009; Cai, Chen, Fang, and Zhou, 2009). Insurance policies can only be designed using past behavior and anticipated changes (such as the use of more fertilizer or switching to a known riskier crop). However if insurance brings about behavioral change that was not anticipated it may no longer be appropriately designed. Because weather securities are more flexible, they may be more robust to such changes.

Before turning to the formalization of the difference between weather securities and standard index insurance, we note that the simplicity and increased flexibility comes with some trade-offs. Faced with multiple products, farmers need to be able to choose the right combination of policies. The weather security approach relies on the idea that farmers know best when and how much rain they need, and therefore what insurance they would like to buy. If this is not the case then it is not clear that a fully flexible approach is better than a product that is designed to be an expert's "best guess" of insurance needs. Basis risk may also be higher given a payout that stays constant regardless of how much below the threshold rainfall fell. The basis risk this induces depends on the type of payouts that are most welfare-improving for farmers. Some studies have suggested that relatively flat payouts made for severe reduction in rainfall are better than tapered payouts.

[1]Given the securities can fit a variety of crop needs in a given area, they have a large client base. This makes the per-unit costs of marketing and design very low. Although in this research, weather securities were marketed to farmers, they also have appeal to others not engaged in farming, but whose livelihoods depend on the weather: e.g. local traders whose volumes depend on the size of the harvest, electricity providers and users whose costs of power creation or usage depend on electricity generated from hydropower.

2.1 A rural economy with weather risk and heterogenous farmers

We first characterize the rural economy in which indexed insurance products are being offered. Our rural economy is populated by farmers who live for two periods and consume and produce a final agricultural commodity. There is no other consumption good other than this agricultural commodity. In period 0 farmers consume and produce the agricultural commodity. Also in period 0 farmers have access to a financial market where they can borrow or save all or part of an initial endowment from period 0 to period 1. The production process takes one period and the final output depends on each farmer's land endowment, input choices and rainfall experience in period 1. In addition we allow each farmer to have access, in period 0, to a market for weather securities where they can insure themselves against rainfall outcomes.

A typical farmer i is endowed with a fixed non-tradable piece of land L_i (the farmer's plot or plots) which is combined with a productive input (I, say fertilizers) in order to farm the agricultural good (y). The production process is as follows. In period 0 farmer i decides on the amount of inputs (I_i) he wants to combine with his land endowment (L_i). There is a competitive market for inputs where farmer i can purchase them at price P_I. In period 1 the farmer's total output (y_i) depends on the amount of realized rainfall at the farmer's plot (θ_i) in period 1 as well as on the amount of inputs chosen in period 0 (I_i) and land endowment (L_i). Input decisions are made at period 0 before rainfall is realized. Hence at period 0 rainfall at a farmer's plot (θ_i) is modeled as a random variable. In particular we model it as a discrete random variable that can take S values $\{R_s\}_{s=1}^{S}$ with probabilities $\{\pi_{is}\}_{s=1}^{S}$. The production function of farmer i is modeled as:

$$y_i = \omega_i(\theta_i) q_i(I_i, L_i), \tag{1}$$

Output is increasing in inputs and land, and marginal products are non-increasing: $\frac{\partial q()}{\partial I_i} > 0$, $\frac{\partial q()}{\partial L_i} > 0$ and $\frac{\partial^2 q}{\partial I_i^2} \leq 0$, $\frac{\partial^2 q}{\partial L_i^2} \leq 0$ for all θ_i.

Farmer i derives utility from consuming the agricultural commodity in period 0 and in period 1. At period 0 the farmer's consumption (c_{0i}) comes from either his initial endowment (y_{0i}) or purchases in the market at price 1, or both. In period 1 the farmer's consumption (c_{1i}) comes from either from own production (y_i) or through purchases in the market also at price

1, or both. For simplicity we do not consider the case of a price that depends on the amount of rainfall experienced by all farmers in a region.[2] The per period utility is defined on the the consumption of the agricultural commodity: $u(c_{ti}),\ t = 0, 1$.

There is a market for a risk-free asset B. In period 0 farmers can save resources by buying risk-free assets at face value 1. This asset yields a net payoff r in period 1. Also farmers can borrow resources in period 0 by selling assets and paying back a net return r in period 1. However we consider limits to the level of borrowing such the level of assets of farmer i (B_i) cannot go below certain exogenous level $-b$: $B_i \geq -b$. In the extreme, no borrowing is possible and $b = 0$.

2.2 Indexed weather securities

In our model farmer i faces a risky outcome as his final output (y_i) depends on the amount of rainfall at his plot (θ_i). In order to allow farmer i to insure against rainfall outcomes we introduce a market for contingent financial assets or weather securities. The payoffs of these assets are linked to the amount of rainfall (or rainfall index) at a nearby weather station, which we label as θ. As in the case of θ_i we model θ as a discrete random variable that can take the same S values $\{R_s\}_{s=1}^{S}$, but with potentially different probabilities $\{\pi_s\}_{s=1}^{S}$. The joint distribution of θ and θ_i is given by probabilities:

$$\pi_{st} = Pr(\theta = R_s \ and \ \theta_i = R_t) \qquad s = 1, ..., S \ \ t = 1, ...S \tag{2}$$

The fact that rainfall at the weather station (θ) might be different than rainfall at the farmer's plot (θ_i) is given by positive probabilities $\pi_{st} = Pr(\theta = R_s, \theta_i = R_t) > 0$ for $s \neq t$. This introduces the concept of "basis risk". If the weather station was located at farmer's plot then θ_i and θ coincides, which implies $\pi_{st} = 0$ for $s \neq t$ and there would be no basis risk.

We consider $S - 1$ weather securities $\{N_s\}_{s=1}^{S-1}$. Security N_s pays 1 (we can make this payout any positive number without loss of generality) at period 1 if $\theta = R_s$, and zero otherwise. Farmer i can buy or sell these securities at period 0 at prices $\{P_s\}_{s=1}^{S-1}$. Hence through trading

[2] This would be an interesting extension of the model that will allow us to capture the fact that several regions in the developing world are not well connected to rest of the economy and therefore prices are determined at a local level. Here our model is one where prices are mainly determined outside our rural economy and therefore are invariant to the local weather conditions.

these assets farmer i can get resources when bad rainfall outcomes are realized. Notice that the overall number of assets available to farmer i is S: $S-1$ contingent assets plus one risk-less asset.

Farmer i maximizes expected utility by deciding consumption in period 0 (c_{i0}), contingent consumption in period 1 for all possible states of nature $c_{i1}(\theta_i, \theta)$, the amount of inputs I_i to combine with his land L_i and purchases of risk-free assets B_i and weather securities $\{N_{is}\}_{s=1}^{S-1}$ Note that a state of nature is a pair of realizations for θ and θ_i and therefore we consider $S \times S$ possible states of nature. The farmer's maximization problem is (for simplicity we drop farmer's index i) :

$$\max_{c_0, c_1, I, B, N_s} EU(c_0, c_1) = u(c_0) + \beta E u(c_1) \tag{3}$$

$$\begin{aligned} s.t. \quad c_0 &= y_0 - (P_I I + B + \textstyle\sum_{s=1}^{S-1} P_s N_s) \\ c_1(\theta_i, \theta) &= \omega(\theta_i) q(I; L) + (1+r)B + \textstyle\sum_{s}^{S-1} I(\theta = R_s) N_s \quad \text{for all } (\theta_i, \theta) \\ B &\geq b, \end{aligned} \tag{4}$$

where $I(\theta = R_s)$ is an indicator function that takes value 1 if $\theta = R_s$, zero otherwise.

2.3 Comparing weather securities with standard index-based insurance scheme

A standard index-based insurance scheme is one in which there is only one (or few at most) contingent asset or insurance policy. This asset N can be purchased in period 0 at price P_N and gives the holder the right to claim contingent payoffs $X(\theta)$, where $X(R_s)$ is the payoff if $\theta = R_s$. In this case the index is θ and typically payoffs are calibrated to compensate farmers for output losses due to inadequate rainfall. For the sake of exposition let's assume there is an adequate rainfall level $\overline{\theta}$ and a corresponding input decision $\overline{I}$, hence one can think of payoffs $X(\theta)$ as deviations $\omega(\theta|\theta = \overline{\theta})q(\overline{I}, L) - \omega(\theta|\theta = R_s)q(\overline{I}, L_i)$. Loosely speaking when there is a bad rainfall outcome (bad meaning a rainfall level which delivers low output) payoffs are high and viceversa. Note that the index-based scheme uses θ as index instead of θ_i; and therefore function ω has θ as argument.

1. **Payoffs under an index-based insurance scheme can be replicated by a weather securities scheme:** We can show that in the absence of borrowing constraints any payoffs $X(\theta)$ under an index-based insurance scheme can be replicated by a portfolio $\alpha = \{\alpha_1, ..., \alpha_S\}$ of the S available financial assets under a weather securities scheme. This is the case as the $S-1$ weather securities plus the risk-free asset are S linearly independent assets (See formal proof in the Appendix)

2. **Any set of contingent payoffs under a weather securities scheme cannot be replicated by an index-based insurance scheme:** In general any portfolio

   $\{N_1, ...N_{S-1}, B\}$

   of weather securities plus the risk-free asset generate contingent payoffs

   $\{N_1 + B(1+r), ..., N_{S-1} + B(1+r), B(1+r)\}$

   that cannot be replicated by a linear combination of the unique set of payoffs $X(\theta)$. Note that payoffs $X(\theta)$ represent a specific vector in a S-dimension space while payoffs under a weather securities scheme can lie anywhere (assuming no borrowing constraints) in the S-dimension space (See formal proof in the Appendix)

What we have shown here is that a standard index-based insurance scheme is a particular case of a more general weather securities scheme as the latter allows for a richer set of payoffs including payoffs $X(\theta)$. As we will discuss below this might be an important feature when different farmers demand different contingent payoffs. However if all farmers demand the same contingent payoffs, and the assumptions of our benchmark case hold, then those payoffs can be achieved under either schemes. For this to happen payoffs $X(\theta)$ must be carefully calibrated.

A natural candidate would be to define: $X(\theta) = [\omega_i(R_S) - \omega_i(R_t)]$. In this case farmer i will be indifferent between being offered a standard index-based insurance scheme and a weather securities scheme. However note that these insurance payoffs are farmer specific. While farmer i will be able to achieve perfect consumption smoothing farmer j will require different insurance payoffs to achieve the same result, in particular farmer j will require $X(\theta) = [\omega_j(R_S) - \omega_j(R_t)]$.

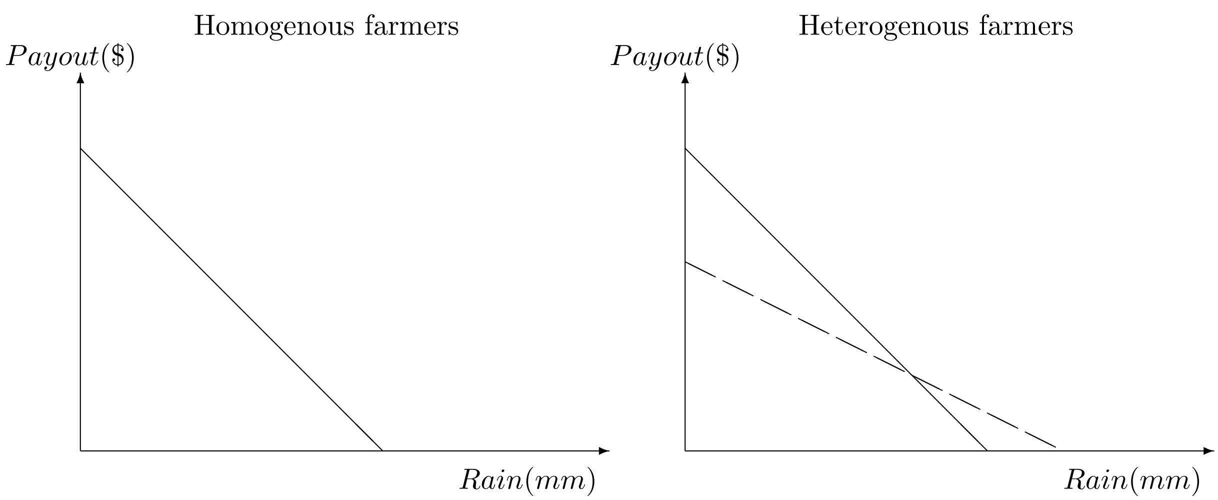
When farmers are heterogenous such that functions $\omega_i(.)$ and $\omega_j(.)$ differ, a standard index-based insurance scheme does not allow all farmers to achieve their optimal farmer specific contingent payoffs. The underlying reason for this is that while a weather securities scheme can accommodate many different contingent payoffs, a standard index-base insurance scheme is one that generates only a particular set of contingent payoffs. Typically in practice these payoffs are calibrated to reflect the contingent payoffs required by a representative or average farmer but not any farmer in particular. Therefore the more heterogenous farmers are the more desirable is a weather securities scheme over a standard index-based insurance.

In our theoretical model, we would require $S-1$ securities in place to generate any set of contingent payoffs and this way accommodate the requirements of any farmer. In practice S might be a very large number as it is related to the number of possible rainfall outcomes, and it is impractical for either farmers or insurance companies to manage portfolios of weather securities of let's say tens, hundreds or thousands. Real world requirements pose limits to the number of weather securities that can be provided. The implication of having a limited number of weather securities is that it is no longer true that any set of contingent payoffs can be achieved and thus it is quite possible that neither separability nor perfect consumption smoothing across states of nature can be achieved. For simplicity we propose only two weather securities: N_1 which pays 1 if $\theta \in \{R_1, ..., R_t\}$, and N_2 which pays 1 if $\theta \in \{R_{t+1}, ..., R_{S-1}\}$.

This immediately highlights the trade-off between a system of weather securities and a single index-insurance policy. An index insurance policy may be able to provide different payoffs across all states, based on the average water requirements assessed from crop models, but it cannot provide different payoff profiles across heterogenous farmers. Weather securities, on the other hand, are flexible in providing different contingent payoff profiles for heterogenous farmers, but cannot provide different payoffs across all states. The trade-off between these two schemes will depend on: (i) the degree of heterogeneity across farmers rainfall needs in a particular locale, and (ii) the costs imposed by a flat payout structure.

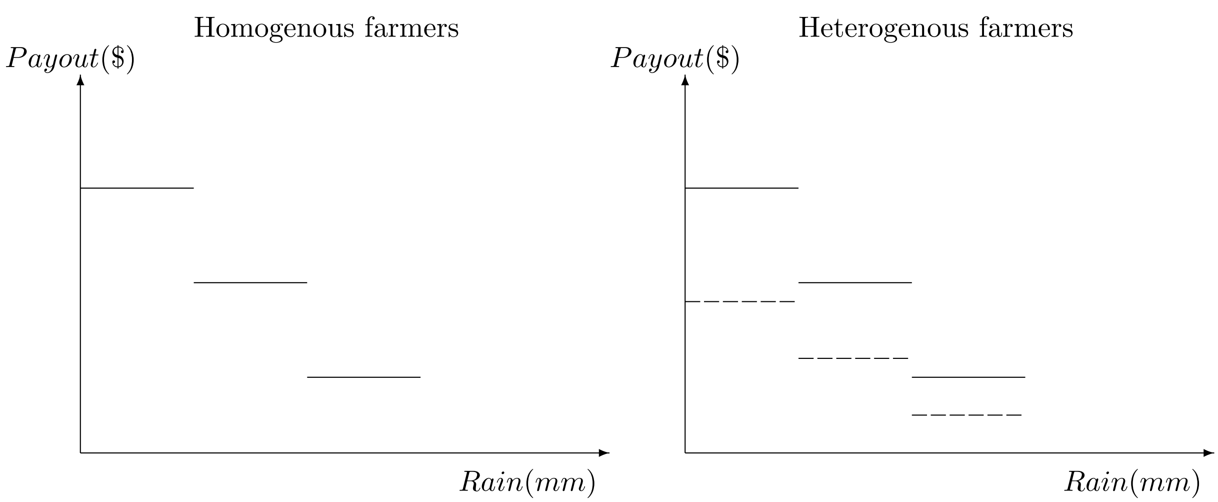
Here we show graphically how a weather securities scheme can respond to the insurance demands of heterogenous farmers and how the capacity to respond to such demands depends on the number of weather securities available. At the same time we show the capacity of a standard index-based approach to respond to insurance demands. In Figure 1 we assume there is a large number of weather securities available, at least as many as possible rainfall outcomes for which positive payoffs are required. Imagine now that all farmers are similar such that they demand the same payoff structure to insure themselves against risky rainfall outcomes and that this optimal payoff structure is like the one represented by the left side of Figure 1. While this payoff structure can be almost replicated by combining many weather securities it can also be provided by a standard index-based insurance policy as long as those who design it have access to the information required to infer that this is the optimal payoff structure. If this is the case then we can see that a standard index-based insurance policy is superior to a weather securities scheme (leaving aside other considerations such as, for example, how easy it is to understand this product among potential buyers). However, given farmers are heterogenous and have differing optimal payoff structures, a single index-based insurance policy can at most perfectly provide the optimal payoff structure for one type of farmer. Or, for no farmers, if the product was calibrated to satisfy the demands of the "average farmer type". As an example on the right side of Figure 1 we show two types of farmers with different optimal payoff structures. In this case, with a large number of weather securities, both payoff structures can be obtained. This case could be generalized for several types of farmers.

Figure 1: Many weather securities



However as we discussed before it is impractical and unrealistic to handle a large number of weather securities and instead only a limited number can be marketed. As an example in Figure 2 we consider only 3 weather securities. In this case, on the left side of Figure 2 we show that with only 3 weather securities the optimal payoff structure required by a group of homogenous farmers is imperfectly approximated, in the form of a step function. Again, a single standard index-based policy can deliver such a payoff profile if well designed. However when we consider heterogenous farmers, as in the right panel of Figure 2, things change. While weather securities cannot perfectly replicate the payoffs structure of any farmer type in particular they can certainly respond, imperfectly, to heterogenous payoffs demands. The more heterogenous are farmers, the more appealing is a weather security scheme relative to a standard index-based policy. And the fewer weather securities available, the more imperfect is the way in which the optimal payoff structure of any particular farmer type can be replicated.

Figure 2: Few weather securities



3 Heterogeneity of rainfall risk in rural Ethiopia

In 2009 we started to test the potential of weather securities. The research was undertaken in Silte woreda, in southern Ethiopia. Two villages were selected from within one kebele to participate in the experiment. Although both villages were selected from the same kebele, there were a number of crops grown in the two villages: barley, wheat and maize being the main staples.

During focus group discussions clear differences in the rainfall needs of different crops in the kebele emerged. There are three main crops grown in this kebele: wheat, maize and barley. Wheat and maize farmers in the lower-lying villages in the kebele required rainfall mid-season and barley farmers in the highland villages required rainfall later in the season. Specifically, wheat and maize farmers were particularly concerned about the amount of rain that would fall in August, whilst the rainfall risk of greatest concern to Barley farmers was how long into September the rains would last.

Focus group discussions also indicated some heterogeneity in rainfall risk among farmers of the same crop based on the type of soil and in the specific production practices farmers employed. In particular, the timing of planting decisions, the investment in land preparation prior to planting and different responses to intermittent or untimely rains during the year. In making these decisions each farmer was combining practices he or she believed to be optimal, techniques he or she had learned from other farmers or extension services, and ultimately his or her best guess as to what the rain was likely to be during the course of the season. Farmers reported that they would also undertake behaviour to limit their exposure to any one aspect of rainfall risk by spreading planting out across the season. It is also quite possible that farmers deliberately take production decisions that differ from their neighbors in order to spread risk across the locally-based risk-sharing groups that are strongly present in this area.

These discussions influenced the design of the securities. They indicated that the three main months of interest were July, August and September, and they indicated that different farmers would require insurance for different months, largely on the basis of the crops they were planting, but also on the basis of soil type and the cropping decisions they had taken that season.

To test these conclusions, quantitative data on individual characteristics and experience of rainfall over time is needed for a large number of households in one location. Prior work in this kebele (Hill and Viceisza, 2010) had resulted in collection of exactly this data: 240 households in this kebele had been surveyed and had provided details on production, plot characteristics and perceptions of the last 5 years of rainfall data.[3] In this section we use this data to test the two main assumptions on which the design of a system of weather securities is premised: (i) farmers in the same geographic location have different rainfall needs given

[3]As part of a prior survey (funded by USAID) conducted in this Kebele.

differing crop portfolios, and (ii) farmers with similar crop portfolios have different rainfall needs on account of differences in plot characteristics and production practices.

Data on perceptions were collected by asking farmers a series of questions in order to quantify their perception of rainfall volatility in the last 5 years. The questions were as follows:

- Question 1: When was the last year in which you received sufficient Kiremt rains (from June to September) for your crops?
- Question 2: When was the last year in which the Kiremt rains failed (from June to September)?

The enumerator was instructed to hand a list of years to the respondent, and a series of cards denoting different numbers of rain drops (from no drops to 8 drops). The enumerator was instructed to place the card with six drops in the year given in response to question 1 and to place the card with one drop on the year given in response to question 2.

- Question 3: If [card showing 6 drops of rain] was the kiremt rains received in [year rain was sufficient] and [card showing 1 drop of rain] was the rainfall received in [year rain failed], how would you describe the kiremt rains in the other years in the last 5 years (for as many as you can remember)?

The enumerator was instructed to place the cards on the year as the respondent selects them and to use multiple copies of a given card if needed.

This data was combined with crop production choices and plot characteristics to assess systematic differences in rainfall perceptions across farmers of different types. Ideally we would have information on production choices over time, but this information was only collected for the prior season (2008). We are implicitly assuming some correlation in production choices across time in this analysis.

In Table 1 we present results assessing whether there is systematic variation in individual perceptions of whether the rains were good or bad. The first column highlights that there is considerable agreement between farmers on which years were good and bad within the kebele (R-squared=0.494). In column 2 we examine how these perceptions vary across cultivators of different crops, by interacting the proportion of the main staple crop grown by the household with year dummies. The results show that there are systematic differences in the perceptions of historical rainfall between barley farmers and other farmers, most likely on account of the fact that barley farmers are much more susceptible to rainfall shortages in September (suggested by the focus group discussions and the estimated rainfall requirements of these crops). The relatively good year of 2004 was worse for barley farmers than other farmers, but the two worst years on average (2005 and 2007) were not as bad. In both 2005 and 2007 rainfall in September was twice the historical average.

We also find that the proportion of wheat or maize grown does not imply significant differences in perceptions of rainfall from the average. In column 3 we re-estimate the regression, just using the proportion of land planted to barley. Although planting land to barley does result in systematic differences, it is worth noting that allowing for this only explains an additional 1% of variation in perceptions.

In Table 2 we include plot characteristics. Households were asked to characterize their soil in terms of three well-known measures of soil quality lem, lem-teuf and teuf, roughly translated as good, reasonable and bad. Most soils within the kebele are lem or lem-teuf and we use the proportion of those reporting not having lem soils as one measure of land quality. The second measure of land quality is given by whether farmers undertake soil conservation on their plot. We find that 72% of farmers undertake soil conservation on their plot to prevent erosion. The majority of those that do not practice soil conservation (86%) report that it is because their land does not suffer from such problems. This measure is thus also an indicator of land quality.

Results in column 2 indicate that both of these measures have a significant impact on historical perceptions of rainfall. Whilst the worst year of this period, 2007, was equally bad (relative to other years) for those that had bad soils, other years fared quite differently. 2008 was an average year for most farmers, but for farmers with poor quality soils it was much worse. Similarly (although not as strong) in 2004. Both 2004 and 2008 were characterized with low rain at the beginning of the season. Poorer quality soils are less able to hold moisture so falls in rainfall at the beginning of the season (after the earlier Belg rains) will be particularly likely to hit farmers with poor quality soils.

Finally, we include the number of extension visits the farmer has received in the 2007-8 season and whether or not the farmer applied fertilizer. For this variable we have information on which year fertilizer was applied. Whilst there is no difference reported in variation for farmers that applied fertilizer, extension visits seem increase the volatility of rainfall experienced: average years are better (2004 and 2008) and bad years (2007) are worse. Whilst it would not be wise to read too much into this result, it is worth noting that this finding would correspond well with a story in which farmers receiving multiple extension visits are farmers that are more likely to undertake more productive, but riskier production practices.

Although based on recall data, these results suggest that susceptibility to rainfall does differ across farmers in intuitive ways on the basis of the crops they plant and their production characteristics. In fact we find that plot and production characteristics contribute 3-4 times more to explaining variation across farmers than do variations in crop choice. These findings have implications for the type and level of insurance coverage that farmers in one location are likely to require, and suggest that flexible insurance products that farmers can purchase according to their own needs may be useful.

4 Description of the experiment and pilot

To test the idea of weather securities, we conducted a real-time experimental game in 2009, and worked with an insurance company, Nyala Insurance Company (NISCO), and the University of Oxford to provide these financial products in 2010.

4.1 Experimental Games in 2009

In 2009, six weather securities were offered to farmers in a real-time experimental game in two villages in Silte woreda in southern Ethiopia. Previous experimental games that have been conducted to assess willingness to pay (Hill, Viceisza, and Deustua-Rossel, 2009; Clarke and Machiavello, 2009) have found very high take-up rates in contrast to very low rates of take-up in reality. This could in part result from abstractions from reality that have to be made in order to conduct the game. Abstractions such as the removal of liquidity constraints, the irrelevance of time preferences, limited need for trust that insurance will pay, use of probability devices rather than real weather outcomes. Whilst some important elements of the game were kept (such as endowing farmers with cash to make the purchases within the game), conducting a game in real time had the advantage of allowing the game to mimic the same time preference, trust and weather expectations as would be present in a real choice.

The six securities offered comprised two securities for each of the three main months of the rainy seasons, July, August and September. In consultation with farmers, local experts, and standard crop models we identified the severe-loss cut-off level for these months. The cut-off was for the rainfall recorded in millimeters at Butajira weather station located some 20km away at the same altitude as one of the villages. The moderate-loss cut-off level was identified as 25mm higher than this. The securities had a fixed payout of 100 Birr (approximately US$9). The back of each security reported historical rainfall information and those years in which the security would have paid 100 Birr over the last 40 years. Each security was priced at its expected value (100 Birr multiplied by the probability the security would pay based on historical data). Table 3 summarizes the security and prices, and the front and back are depicted in the Annex.

From each village individuals and groups were randomly selected to participate. Indigenous funeral associations (called iddirs) are very strong in this area and provide insurance for the costs of funerals, as well as health-care loans and livestock insurance to members. Whilst these associations are inclusive of all households in the village, leadership of these groups often includes individuals that have above-average financial literacy. Leaders are required to keep accounts and determine how much can be paid out in the event of a funeral or other event. We randomly selected 12 iddirs (comprising 349 households) out of the 16 that existed in these two villages and 24 individual farmers from the 4 non-selected iddirs.

There were thus three categories to which individuals in these two villages belonged: those selected to participate through their iddir (the majority), those selected to participate as individuals, and those who were not selected to participate. The allocation of households across these groups is indicated in Table 4.

An endowment was provided to each member of the selected iddirs, and to each selected individual. This endowment was randomly assigned (although held constant within one iddir), and ranged from 30 to 60 Birr per farmer. On average 44 Birr was endowed per individual. Farmers were free to keep the endowment or to use it to buy weather securities. As the securities were priced at their expected value, the endowment and securities had the same value in expectation. Participants were provided training and then were given two opportunities to purchase securities at two "buying days" held in the following month. Any endowment that was not spend on securities was given in cash to participants after the end of buying on the second day.

All participants were informed that in mid October 2009 all payouts will be distributed. The rainfall was such that two of the six securities paid out. In the third weekend of October 2009 money payouts were distributed to all participants holding securities for which payouts were triggered.

All households in the two villages were surveyed in a follow-up survey conducted at the end of the experimental period (after payouts in October).

4.2 Insurance pilot in 2010

In 2010, based on the strong levels of understanding and demand that were they observed in the experimental game, NISCO provided weather securities for the months of June, July, August and September in this and other nearby kebeles.[4] Again two securities were provided for each month, but this time both securities were cumulative over the tail of the distribution, in that the moderate security covered from 0 to the moderate cut-off, not from the severe-cut-off to the moderate cut-off. Again the securities were priced at their expected value.[5] However this time farmers who bought the securities paid from their own pocket, and the securities were also for larger amounts of money with each security paying out 500 Birr in the case the event it was designed to cover came to pass. The characteristics of the securities provided are detailed in Table 5.

A survey of 480 randomly selected farmers in 24 villages was conducted to examine uptake and purchase patterns. There was also an encouragement design mechanism embedded in the 2010 experience, and this is described and analyzed in Clarke, Dercon, Hill, Outes-Leon, Seyoum Taffesse (2010). In this paper we examine how security choices vary with production and plot characteristics.

[4] NISCO had sent one of their staff members to observe the training session and the buying days that took place in 2009.

[5] IFPRI and NISCO participated in and won a competition prize for the weather securities concept in the Marketplace for Financial Innovations hosted by AfD, the World Bank and the Gates foundation in Paris 2010. This money was used to finance the additional costs of provision such as the design of the securities, the training, the reinsurance and the costs involved in issuing and reimbursing the insurance policies.

5 Understanding in the experimental game

The experimental game conducted in 2009 provided some insight on how well these securities were understood, and how understanding varied with training type.

All participants in the experimental game were provided training, but in the case of iddirs only three representatives (selected by iddir members) attended the training. These representatives were also the representative that could make purchases on behalf of the group members during the buying days. No further restrictions were placed on how the iddirs distributed information and made decisions on purchases.

Those that participated as individuals undertook the same training as iddir leaders, they attended a training session, and two buying days in which additional explanation was also given as requested. They also purchased the securities themselves and attended the session in October to receive payouts.

There was thus a substantial difference in the type of training and participation of those that participated through their iddir and those that participated as individuals. Individuals that participated through their iddir elected three representatives of the iddir that would participate in the training sessions and convey information back the group if needed. These representatives would also be the ones purchasing the insurance, taking the remainder of the endowment back to households, and receiving any payout of the securities purchased in order to distribute to group members. The group was thus required to elect individuals that it trusted to understand the insurance being offered, to communicate information learned, and to be trustworthy with the money and securities they handled. There was little direct interaction between the project staff and those participating through their iddir but not elected as representatives. The interaction was limited to the village wide meeting conducted at the beginning of the project. This was the same level of interaction and explanation as for those not selected to participate.

All participants were asked a number of information and understanding questions about the securities in the follow-up survey. Overall, we find the products were quite well understood. Of those trained, more than three-quarters were able to know the conditions on which the security paid and how much it would pay.

We would expect the level of understanding to differ across individuals based on their level of participation and their level of education. Descriptive statistics on levels of understanding are presented for different categories of participant in Table 6. Regression results on the determinants and correlates of understanding are presented in Table 7.

In column (1) we see that participation and attending training had a large impact on whether or not an individual understood the financial product being offered. Individuals that participated either as individuals or through their iddir had a much higher level of understanding than those who did not participate in the pilot. They answered between 1.7 and 4 more questions correct than those that did not participate. Those who attended the training answered the most number of questions correctly, and this was particularly the case for iddir representatives in the training. Iddir representatives that attended the training answered two more questions correctly than those participating as individuals. However this was a non-random group and the higher understanding could largely reflect a higher level of education or aptitude of those selected rather than indicating that training had a larger effect for these individuals.

In column (2) we add iddir fixed effects, but find that this does not increase the adjusted R-squared of the regression by much at all indicating that it is individual characteristics (or the interaction of individual and group characteristics) that are driving most of the remaining unexplained variation.

In column (3) we include individual characteristics in the regression. Adding these in increases the adjusted R-squared by 6 percentage points and, as expected, reduces the difference between those randomly selected to participate in training and those selected by their iddir to attend training. As hypothesized iddir representatives selected to attend the training were those that were considered most likely to learn about the new financial tool being introduced.

One interesting finding of these first simple regressions is that the understanding of individuals is not so different from the understanding of group members trained by their leaders. This is particularly true when we add in either iddir fixed effects or individual characteristics.

Additional information was collected on whether iddir leaders conducted a meeting to discuss the weather insurance being offered or whether individuals were informed through informal conversations. Four of the twelve iddirs that participated conducted an iddir-wide meeting to discuss the product after training, in the other eight iddirs information was passed on through informal discussions. Information was collected for all individuals on their attendance at iddir meetings, so we include in the regression a dummy that takes the value 1 if an individual attended all iddir meetings in the last year. Attendance at meetings is required and often enforced with fines, and 75% of individuals attended all the meetings of their iddir in the last year. We interact this dummy with whether or not the group held a group meeting.

People who more regularly attend iddir meetings were more likely to have a good understanding of the securities being offered than those who had missed a meeting in the last year. Those who attend meetings and were members of one of the four iddirs that held a meeting to explain the securities being offered, had a much higher level of understanding than those who had not attended meetings held or those who were in an iddir that had not held meetings. They were likely to answer 2.9 more questions correct than those in the control group, and seemed to have a better understanding than those who participated as individuals.

To test whether those trained by their group leaders do have a better understanding than those who participated in the project as individuals we run the regression again excluding the control households. The omitted group against which the others are being compared is now those that participated as individuals. Taking this as the comparison group we see that there are two groups that had a better understanding of the contract being offered: those who were selected to represent their group, and those who attend iddir meetings and were members of one of the four iddirs that held a meeting to explain the securities being offered. This has an interesting implication for designing future training strategies. It suggests that training representatives selected by the group and encouraging them to train their members may be more effective than training each person in the village directly.

What is clear from this description of understanding is that key features of the insurance were simple enough to be effectively passed on in subsequent training and conversations carried out by the trainees.

6 Empirical analysis of demand for weather securities

In both the experimental game and the pilot insurance purchases were quite high. High take-up rates were not surprising in the experimental game as money had been given for free; but the strong take-up rates recorded in the pilot was encouraging (20% of farmers that were trained on insurance concepts and weather securities purchased at least one security). Table 8 reports the types of securities and combinations bought in the game and the pilot. For the analysis we consider the determinants of each month purchased.

Section 2.2 indicated that rainfall requirements vary across farmers within close geographic areas. These variations should also result in variation in the type of securities purchased among farmers. We would, for example, expect that the type of securities bought by barley farmers and farmers with poor quality land to be quite different from those bought by wheat farmers or those with good quality land. We would also expect that farmers receiving extension visits or using more modern techniques of production would be more likely to purchase more insurance in general, and perhaps also different types of insurance. This is something that we explore using both the experimental and actual purchase data.

However we first describe how decisions were made with the group in the experimental game as this has a bearing on how the data is analyzed.

6.1 Decision Making in the experimental game

No restrictions were placed on the participation of iddirs and how the purchase decisions were to be made. The securities were not issued in the name of an individual. Despite the fact that no restrictions were imposed, there was considerable convergence in how iddirs made the decision about what insurance to purchase. Most iddirs reported that the decision of which securities to purchase was made on behalf of the whole group. In some cases individuals reported submitted their requests to iddir leaders, but the securities to purchase were purchased on behalf of the group rather than individuals purchasing their own securities. There was some difference of opinion reported by group members as to how decisions were made. 62% of individuals reported that the decision was made by the iddir leaders whilst 38% reported that decisions were made by voting or consensus. This variation was quite consistent within iddirs also. In only 2 iddirs was it clear (90% or more of members reporting) that the decisions was taken solely by the leaders.

All individuals were asked to categorize their role in the decision making process. The categories and responses are listed in Table 9. Very few people, 5% of respondents, reported that the final decision was theirs and reflected their choice. An additional 11% of household reported being involved in the decisions even if the final decision would not have been their choice. 30% reported they were involved in the discussions but not the decision, another 30% reported they were informed but not involved in the discussions and 24% reported that they were not involved at all.[6]

In some cases when the securities were bought they were distributed to members, in other cases they were kept by the iddir leaders. A number of iddirs reported keeping the securities in the iddir safe box. When they were distributed to members the members returned them to the iddir leaders for payout. Nearly all iddirs reported that payouts were distributed by the leaders personally and the payouts were distributed equally among members. In one iddir it was agreed that they would keep the payout as part of the savings of the iddir. In most cases iddirs did not decide before hand how the payout would be distributed. In 3 of the 12 iddirs the equal payout rule was agreed to in advance and was known by more than half of the members.

The fact that individuals within an iddir made joint decisions on what to buy, and shared the tickets equally, means that it is most accurate to think of the contracts each iddir bought as one purchase decision. This essentially compresses 349 potential purchase decisions into 12 purchase decisions. As a result the analysis of variations in purchases in the pilot is conducted to allow further formulation of hypothesis testing, rather than provided the data needed to test hypotheses.

6.2 Amount of insurance purchased

In the experimental game, endowments and assignment to group versus iddir were randomly allocated. With 35 effective observations there is little variation or power to explore the impact of this exogenously induced variation. However, as Table 10 shows, total endowment allocated was a strong predictor of the amount of insurance purchased. All individuals that were offered securities in the experimental game were also given the opportunity to purchase securities one year later. Although all individuals in the experimental game purchased at least one (and often

[6] In order to understand who was likely to be involved in the decision-making process, we explore correlates of involvement. People who were more involved in making the decision understood the product better, were members of iddirs that had conducted meetings to make the decision, and were individuals that were more likely to attend iddir meetings. Leaders were much more likely to be actively involved in the decision, but not the chairmen or vice-chairmen. Those most involved in making the decisions were treasurers, secretaries and member controllers. Those with larger farms were also more involved.

two or three securities) very few of these individuals purchased securities in the following year (11% of those that were informed about the securities being offered, which is lower than the overall take-up rate of 19% for all 24 kebeles). This was despite two of the securities having paid out in the previous years, and the clear benefits of weather insurance being realized. When surveyed after the experimental game 97% of households would purchase securities if they were again given money to purchase, and 67% said they would purchase securities if they had to pay out of their own pocket.

Although the experimental game mimicked real life in a way that few other insurance games have (decisions were made over the course of a month, there was a clear opportunity cost to purchasing the insurance, individuals had to trust the weather station and that IFPRI would show up to pay again in the future) it was still limited in capturing key elements of how individuals would behave in real market situations. There are feasible explanations that would explain the difference such as liquidity constraints, larger contract sizes, expectation of future benefit from playing "right"; but it does raise questions over the power of experimental games in predicting real world purchase behaviour.

We now turn our focus to the analysis on variations in the type of insurance purchased.

6.3 Determinants of choice between securities

Tables 11 and 12 present results for the experiment on the determinants of crop choice, and Table 13 presents results for the pilot. In the case of the experiment two tables are presented, one using individual level data (Table 11), and one aggregating at the group level (Table 12). We aggregate at the group level because the previous subsection showed than many of the decisions were taken by a few people on behalf of the whole group. In each table we also present results just using information on characteristics of the training session participants (presented in the even columns).

Given the low number of individual observations we use the results in Tables 11 and 12 to further develop hypotheses, rather than to test them. We find that although those planting a larger area to barley were more likely to purchase September securities, the effect is not significant and they were more inclined to purchase more securities. Indicators of poor soil quality (in this case whether or not an individual undertakes soil conservation) made an individual more inclined to purchase securities for the beginning of the season, even after controlling for crop type. In the individual level experiments visits from extension agents make you more likely to spend more on insurance (reflecting the higher level of risk experienced by households that are often visited by extension agents in this locale), and in particular on September securities.

In the pilot, staple crop choice did not affect which farmers purchased insurance, but it did affect which insurance farmers bought.Farmers who grow barley were much more likely to purchase securities for September and much less likely to purchase securities for July and August. Again, whilst the type of fertilizer used in the previous season had no impact on whether or not a farmer decided to purchase insurance, it did influence which securities a farmer was likely to buy. Those with poor soil quality were more likely to buy insurance, and this was driven by the greater likelihood of these farmers to purchase insurance for the early part of the season, just as in the experimental game.

It is probably more correct to think of the securities purchased as a selection of a portfolio, rather than four independent decisions. To allow for this we re-estimate the linear probability models using a seemingly unrelated regression estimation, which allows the error terms to be joint. We present these results in Table 14. Interestingly, we find almost no difference in the empirical results as a result of estimating in this way.

In summary, we do find that the patterns found in the analysis of weather patterns are reflected in purchases of securities. The results in the tables show that crop and production choices and soil characteristics do have some explanatory power for security choices.This is stronger in the pilot, most likely because the pooled nature of transactions in the experimental game resulted in little variation to exploit.

7 Conclusion

In this paper we have motivated the development of a market of simple-indexed weather securities to replace a more traditional index-insurance contract. We developed a theoretical model to outline the conditions in which weather securities could outperform crop-specific weather index based insurance policies. Data collected during an experimental game and real purchases of such insurance policies among farmers in southern Ethiopia suggests that these securities can be easily-understood and can fit heterogeneous farmer needs. The demand among farmers told about the product (20%), was found to be much higher than in other weather-index insurance pilots (about 10% on average).

We documented how rainfall needs farmers face vary across crop and other characteristics, and found that some of these factors also explained purchases of weather securities in the pilot. To the extent that the results show substantial heterogeneity in rainfall needs and purchases within quite small locales, it motivates further work on these as useful insurance tools for rural farmers.

In documenting the level of understanding of securities among participants we also characterized the transmission of information about weather securities among members of endogenously formed risk sharing groups. We found that training leaders of these groups and encouraging these leaders to train their members, was more effective than training randomly selected individuals.

However, whilst these risk management tools may prove more appropriate than traditional index-insurance approaches for heterogenous populations characterized by low levels of financial literacy, they are not perfect insurance instruments. The heterogeneity found among farmers within these locales, highlights the degree to which basis risk will continue to be a problem for any weather-indexed product. With such potentially high levels of basis risk, serious thought needs to be given to how to use flexible and simple index products to strengthen other forms of insurance such as group-based risk sharing, savings, credit. Further research is needed to understand how to integrate index-insurance with other mechanisms that farmers currently use to mitigate the adverse impacts of risk may help in minimizing this basis risk. In particular by considering how to integrate index insurance with the group-based savings, gifts and loans that are used by farmers to manage idiosyncratic shocks (Clarke and Dercon, 2009).

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A Appendix

A.1 Payoffs under an index-based insurance scheme can be replicated by a weather securities scheme

We assume here no borrowing constraints and no restrictions to short selling of weather securities. Given that both an index-based insurance scheme and a weather securities scheme define contingent payments over realizations of the index θ (rainfall at the weather station) there are S relevant states of natures given by realizations $\{R_s\}_{s=1}^{S}$. We construct a matrix P of payoffs for the $S-1$ weather securities and the risk-free asset:

$$P = \begin{pmatrix} 1 & 0 & 0 & \dots & 1+r \\ 0 & 1 & 0 & \dots & 1+r \\ 0 & 0 & 1 & \dots & 1+r \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & 1+r \end{pmatrix} \tag{5}$$

P is a SxS matrix with each column representing the S contingents payoffs of a particular asset. The last column are the payoffs of the risk-free asset. A portfolio θ of weather securities plus the risk-free asset has gross payoffs $P \cdot \alpha$. Now consider the contingent gross payoffs $X(\theta)$ of an index-based scheme. There exists a portfolio $\alpha^* = P^{-1} \cdot X(\theta)$ of weather securities and risk-free asset with gross payoffs $X(\theta)$:

$$P \cdot \alpha^* = PP^{-1} \cdot X(\theta) = X(\theta) \tag{6}$$

where

$$P^{-1} = \begin{pmatrix} 1 & 0 & 0 & \dots & \frac{-1}{1+r} \\ 0 & 1 & 0 & \dots & \frac{-1}{1+r} \\ 0 & 0 & 1 & \dots & \frac{-1}{1+r} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & \frac{1}{1+r} \end{pmatrix} \tag{7}$$

Note also that if $X(R_S) = 0$ and all other payoffs $X(\theta)$ are positive then the portfolio

α^* implies non-negative asset holdings (no short selling and no borrowing are required)

A.2 Any set of contingent payoffs under a weather securities scheme cannot be replicated by an index-based insurance scheme

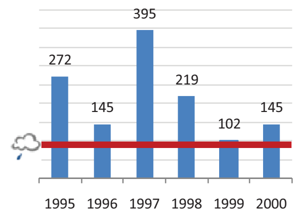
As shown above any non-negative payoffs $X(\theta)$ of an index-based insurance scheme can be replicated by a weather securities scheme. An index-based insurance scheme can generate payoffs that are (positive) linear combination of $X(\theta)$: $\{NX(\theta) : N \in \mathbb{R}_+\}$. Let's consider the following payoffs of a weather securities scheme $X(\theta) + \varepsilon(\theta)$, such that $\varepsilon(\theta)$ is not a linear combination of $X(\theta)$. Then by construction $X(\theta) + \varepsilon(\theta)$ is not in the set $\{NX(\theta) : N \in \mathbb{R}_+\}$.

100

This ticket will pay **100 Birr** if the amount of rain that falls at Butajira weather station

- from **Sane 24th, 2001 to Hamle 24th, 2001**
- is less than **100mm**

DMJ1XXX



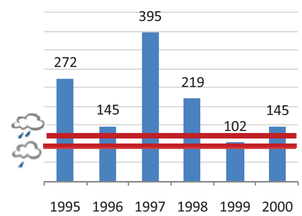
This ticket would have paid in:
1965
1969
1974
1975
1987
1988
1992

125

This ticket will pay **100 Birr** if the amount of rain that falls at Butajira weather station

- from **Sane 24th, 2001 to Hamle 24th, 2001**
- is between **100mm** and **125mm**

DMJ2XXX



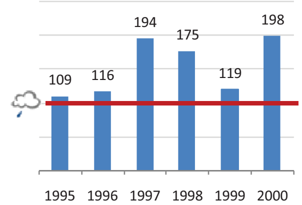
This ticket would have paid in:
1964
1970
1976
1999

100

This ticket will pay **100 Birr** if the amount of rain that falls at Butajira weather station

- from **Hamle 25th, 2001 to Nahase 25th, 2001**
- is less than **100mm**

DMA1XXX



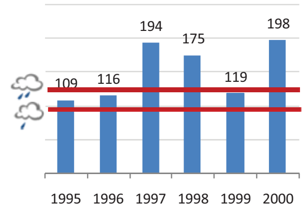
This ticket would have paid in:
1969
1970

125

This ticket will pay **100 Birr** if the amount of rain that falls at Butajira weather station

- from **Hamle 25th, 2001 to Nahase 25th, 2001**
- is between **100mm** and **125mm**

DMA2XXX



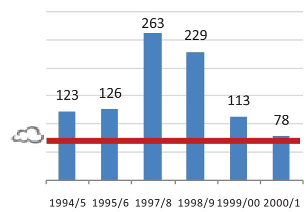
This ticket would have paid in:
1965
1978
1979
1986
1987
1995
1996
1999

75

This ticket will pay **100 Birr** if the amount of rain that falls at Butajira weather station

- from **Nahase 26th, 2001 to Meskerem 20th, 2001**
- is less than **75mm**

DMS1XXX



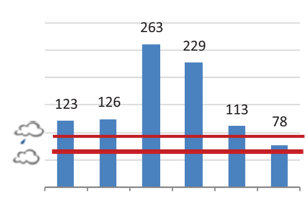
This ticket would have paid in:
1965/66
1969/70
1974/75
1975/76
1987/88
1988/89
1992/93

100

This ticket will pay **100 Birr** if the amount of rain that falls at Butajira weather station

- from **Nahase 26th, 2001 to Meskerem 20th, 2001**
- is between **75mm** and **100mm**

DMS2XXX



This ticket would have paid in:
1964/65
1970/71
1976/77
2000/01

Tables

Table 1: Weather perceptions in one kebele: year and crop variations

	(1)	(2)				(3)	
	Year only	Year and Crop+				Year and Barley Only+	
		Year	Barley	Wheat	Maize	Year	Barley
2004			-1.530**	-0.110	-1.190		-1.281**
			(0.759)	(0.482)	(1.297)		(0.646)
2005	-1.002***	-1.665***	1.996***	0.559	1.739	-1.278***	1.388**
	(0.147)	(0.307)	(0.755)	(0.472)	(1.280)	(0.173)	(0.643)
2006	0.658***	0.485	0.154	-0.510	0.452	0.491***	0.366
	(0.146)	(0.298)	(0.719)	(0.456)	(1.252)	(0.170)	(0.627)
2007	-3.775***	-4.188***	2.103***	-0.249	-0.065	-4.147***	2.248***
	(0.146)	(0.297)	(0.716)	(0.454)	(1.249)	(0.170)	(0.626)
2008	-0.530***	-0.507*	-0.839	-0.258	-2.577**	-0.634***	-0.314
	(0.146)	(0.297)	(0.716)	(0.454)	(1.249)	(0.170)	(0.626)
Constant							
Observations	1167	1163				1163	
Adj. R-squared	0.494	0.504				0.505	

Notes: +Each cell entry represents the coefficient of the crop interacted with the year dummy, all interactions were included in the same regression with the year dummies.
* Indicates significant at 10%, ** at 5% and *** and 1% levels of significance.

Table 2: Weather perceptions in one kebele: including plot and production characteristics

	(2)				(3)					
	Including soil characteristics				Including soil and production characteristics					
	Year	Barley	Not Lem	Soil Cons.	Year	Barley	Not Lem	Soil Cons.	Extension	Fertilizer
2004		-1.269**	0.179	-0.498**		-1.190*	0.145	-0.512**	0.813***	0.210
		(0.632)	(0.232)	(0.226)		(0.653)	(0.230)	(0.225)	(0.208)	(0.220)
2005	-0.756**	1.109*	1.323***	-0.441**	0.066	1.257*	1.348***	-0.413*	-0.105	-0.236
	(0.332)	(0.628)	(0.229)	(0.224)	(0.396)	(0.648)	(0.227)	(0.222)	(0.206)	(0.216)
2006	0.295	0.296	0.431*	-0.059	0.827**	0.196	0.414*	-0.078	0.049	0.145
	(0.328)	(0.611)	(0.223)	(0.221)	(0.391)	(0.630)	(0.222)	(0.220)	(0.201)	(0.211)
2007	-4.842***	2.228***	-0.106	0.279	-3.987***	1.959***	-0.094	0.268	-0.482**	0.202
	(0.326)	(0.610)	(0.222)	(0.220)	(0.388)	(0.623)	(0.220)	(0.218)	(0.199)	(0.202)
2008	-0.544*	-0.074	-0.537**	-1.098***	-0.376	-0.021	-0.584***	-1.129***	0.621***	0.173
	(0.326)	(0.610)	(0.222)	(0.220)	(0.387)	(0.620)	(0.221)	(0.218)	(0.199)	(0.199)
Constant										
Observations	1163				1163					
Adj. R-squared	0.533				0.544					

Notes: +Each cell entry represents the coefficient of the crop interacted with the year dummy, all interactions were included in the same regression with the year dummies.
* Indicates significant at 10%, ** at 5% and *** and 1% levels of significance.

Table 3: Characteristics of securities offered in 2009

Security	Ticket pays 100 Birr if the amount of rainfall at Butajira weather station in period (A) is (B):		Price
	Time period (A)	Rainfall range (B)	
Ticket 1 (Pink 100)	July	less than 100mm	18 Birr
Ticket 2 (Pink 125)	July	between 100mm and 125mm	10 Birr
Ticket 3 (Blue 100)	August	less than 100mm	5 Birr
Ticket 4 (Blue 125)	August	between 100mm and 125mm	21 Birr
Ticket 5 (Green 75)	September	less than 75mm	18 Birr
Ticket 6 (Green 100)	September	between 75 and 100mm	10 Birr

Table 4: Allocation of households in the experimental game

	Mukhere village	Edo village	Total
Total households surveyed	210	196	406
Number:			
participating as an individual	6	17	23
participating through iddir	194	149	343
not participating	10	30	40

Table 5: Characteristics of securities offered in 2010

Security	Ticket pays 500 Birr if the amount of rainfall at Butajira weather station in period (A) is (B):		Price
	Time period (A)	Rainfall range (B)	
June (50 Birr)	June	less than 56mm	50 Birr
June (100 Birr)	June	less than 69mm	100 Birr
July (50 Birr)	July	less than 97mm	50 Birr
July (100 Birr)	July	less than 116mm	100 Birr
August (50 Birr)	August	less than 96mm	50 Birr
August (100 Birr)	August	less than 114mm	100 Birr
September (50 Birr)	September	less than 61mm	50 Birr
September (100 Birr)	September	less than 79mm	100 Birr

Table 6: Understanding of securities

	Proportion getting the question correct					
	Total sample	Individual	Group			Control
			Total	Group rep.	Ordinary member	
Months securities offered for	66%	87%	69%	97%	66%	30%
The securities pay on the basis of rainfall recorded at the weather station, not your own field	89%	96%	90%	100%	89%	73%
A farm at the weather station would not receive the same rainfall as you	69%	57%	68%	68%	68%	83%
If it rained 79mm in Hamle, the Pink 100 security would have paid	46%	74%	47%	82%	43%	25%
Average number answered correctly	3.1	3.4	3.3	5.4	3.0	1.3

Table 7: Characteristics of understanding: regressing the understanding score on nature of participation

	(1)	(2)	(3)	(4)	(5)
Participated as an individual	2.110***	2.104***	1.797***	1.853***	
	(0.497)	(0.498)	(0.484)	(0.468)	
Participated as a group and were trained	4.028***	4.394***	3.397***	3.561***	1.787***
	(0.443)	(0.701)	(0.479)	(0.466)	(0.556)
Participated as a group and were not trained	1.698***	2.040***	1.749***		
	(0.319)	(0.628)	(0.313)		
Group held meeting & they attended all meetings last year				2.920***	1.036**
				(0.389)	(0.465)
Group held meeting & they missed a meeting last year				1.551***	-0.170
				(0.486)	(0.564)
Group did not hold a meeting				1.633***	-0.211
				(0.309)	(0.403)
Attended all meetings last year				0.472*	0.605**
				(0.258)	(0.273)
Years of education			-0.002	-0.013	-0.004
			(0.038)	(0.037)	(0.038)
The father was an important person			0.986***	0.776***	0.821***
			(0.199)	(0.200)	(0.216)
The head holds an official position			0.477	0.512	0.562
			(0.328)	(0.321)	(0.354)
Iddir judge			-0.593	-0.593	-0.771
			(0.545)	(0.528)	(0.613)
Iddir vice-judge			0.358	0.193	0.351
			(0.581)	(0.568)	(0.604)
Iddir secretary			0.470	0.298	0.253
			(0.572)	(0.556)	(0.572)
Iddir treasurer			0.428	0.288	-0.199
			(0.668)	(0.647)	(0.704)
Other iddir office-bearer			0.661	0.497	0.642
			(0.656)	(0.635)	(0.691)
Sample	Full	Full	Full	Full	Not control
Observations	406	406	401	401	361
Adjusted R-squared	0.166	0.165	0.225	0.276	0.233

Notes: * Indicates significant at 10%, ** at 5% and *** and 1% levels of significance.

Table 8: Purchases of securities

Security	Number purchased	Proportion of farmers purchasing	Total
Experimental game in 2009			
July (100 mm)	152	41%	2,736 Birr
July (100 to 125 mm)	113	30%	1,130 Birr
August (100 mm)	249	67%	1,245 Birr
August (100 to 125 mm)	17	5%	357 Birr
September 75 (75 mm)	104	28%	1,872 Birr
September 100 (75 to 100 mm)	142	37%	1,420 Birr
Total	*777*	*100%*	*8,760 Birr*
Pilot in 2010 (numbers from 480 surveyed households only)			
June (50 Birr)	43	9%	2,150 Birr
June (100 Birr)	8	2%	800 Birr
July (50 Birr)	16	3%	800 Birr
July (100 Birr)	5	1%	500 Birr
August (50 Birr)	32	7%	1,600 Birr
August (100 Birr)	9	2%	900 Birr
September (50 Birr)	31	6%	1,550 Birr
September (100 Birr)	4	1%	400 Birr
Total	*148*	*27%*	*8,700 Birr*

Table 9: Involvement in decision-making

How would you characterize your role in the decision-making process?	%
Very involved in the discussions and decision, the final decision reflected my choice	5
Involved in the discussions and decision, but the final decision did not reflect my choice	11
Involved in the discussions but not the decision	30
I was informed but not involved in the discussions	30
Not involved at all	24

Table 10: Regressions on the amount of insurance purchased

	(1) Amount spent	(2) Amount spent
Endowment	0.205*	0.288**
	(0.105)	(0.112)
Number of people in group	15.252***	14.710***
	(4.387)	(4.470)
Proportion of barley		-10.292
		(97.243)
Proportion of wheat		-125.912
		(184.352)
Proportion of maize		-2,209.220*
		(1,184.910)
Proportion of land not lem		-2.176
		(30.759)
Undertakes soil cons.		-12.159
		(74.557)
Number of extension visits		6.419
		(35.956)
Constant	-7.416	7.127
	(27.131)	(58.853)
Observations	35	34
Adjusted R-squared	0.879	0.881

Notes: * Indicates significant at 10%, ** at 5% and *** and 1% levels of significance.

Table 11: Security choices in 2009 (individual data)

	(1) Total tickets	(2) Total tickets	(5) July	(6) July	(3) August	(4) August	(7) September	(8) September
Proportion of barley	0.252	0.873**	0.057	0.477	0.105	0.030	0.091	0.366
	(0.212)	(0.348)	(0.136)	(0.326)	(0.091)	(0.224)	(0.235)	(0.445)
Proportion of wheat	-0.184	-0.287	-0.004	0.002	-0.150	-0.322	-0.031	0.033
	(0.379)	(0.552)	(0.172)	(0.313)	(0.154)	(0.224)	(0.258)	(0.381)
Proportion of maize	-0.824	-4.171***	-0.112	-1.165	-0.397	-0.825	-0.315	-2.181
	(0.487)	(1.251)	(0.153)	(0.811)	(0.335)	(0.656)	(0.255)	(1.553)
Proportion of land not lem	-0.008	0.051	-0.001	-0.001	-0.004	0.042	-0.003	0.010
	(0.061)	(0.067)	(0.021)	(0.052)	(0.027)	(0.034)	(0.027)	(0.075)
Undertakes soil cons.	-0.147	-0.020	0.162*	0.373***	-0.068	-0.107	-0.241	-0.286*
	(0.112)	(0.236)	(0.081)	(0.135)	(0.052)	(0.119)	(0.146)	(0.164)
Number of extension visits	0.027	0.114***	0.001	-0.010	-0.039	0.020	0.065*	0.104*
	(0.035)	(0.036)	(0.016)	(0.033)	(0.040)	(0.021)	(0.034)	(0.057)
Uses fertilizer	0.049	-0.322	0.090	0.023	0.001	-0.068	-0.042	-0.277
	(0.203)	(0.259)	(0.081)	(0.140)	(0.089)	(0.152)	(0.123)	(0.211)
Sample	all	trainees	all	trainees	all	trainees	all	trainees
Observations	337	53	337	53	337	53	337	53
Adjusted R-squared	0.023	0.138	0.041	0.029	0.050	-0.015	0.027	-0.005

Notes: * Indicates significant at 10%, ** at 5% and *** and 1% levels of significance.

Table 12: Security choices in 2009 (group data)

	(1) Total tickets	(2) Total tickets	(3) July	(4) July	(5) August	(6) August	(7) September	(8) September
Proportion of barley	0.528	0.599	0.271	0.323	-0.297	-0.219	0.554	0.495
	(0.372)	(0.400)	(0.388)	(0.388)	(0.236)	(0.251)	(0.556)	(0.548)
Proportion of wheat	-0.072	-0.697	-0.409	-0.211	-0.396	-0.583*	0.732	0.097
	(0.806)	(0.727)	(0.733)	(0.464)	(0.508)	(0.336)	(1.134)	(0.649)
Proportion of maize	-9.336**	-4.265	1.536	-1.747	-4.568	-0.278	-6.304	-2.240
	(3.535)	(2.914)	(3.164)	(2.233)	(3.501)	(1.593)	(5.349)	(3.893)
Proportion of land not lem	0.137	0.058	-0.124	-0.070	0.081	0.083	0.180	0.045
	(0.109)	(0.088)	(0.098)	(0.107)	(0.067)	(0.069)	(0.182)	(0.197)
Undertakes soil cons.	-0.161	-0.124	0.590**	0.556**	-0.209	-0.216	-0.543	-0.464
	(0.423)	(0.383)	(0.257)	(0.208)	(0.211)	(0.200)	(0.439)	(0.293)
Number of extension visits	0.259	0.230*	-0.054	-0.055	0.040	0.057	0.273	0.229
	(0.202)	(0.121)	(0.137)	(0.111)	(0.112)	(0.062)	(0.257)	(0.140)
Uses fertilizer	-0.410	-0.346	0.051	0.065	-0.042	-0.010	-0.419	-0.401
	(0.274)	(0.321)	(0.250)	(0.220)	(0.153)	(0.192)	(0.363)	(0.311)
Characteristics are an average for	All group members	Trained members	All group members	Trained members	All group members	Trained members	All group members	Trained members
Observations	34	34	34	34	34	34	34	34
Adjusted R-squared	0.120	0.109	0.016	0.002	0.061	-0.023	0.009	-0.030

Notes: * Indicates significant at 10%, ** at 5% and *** and 1% levels of significance.

Table 13: Security choices in 2010

	(1) Individual purchased insurance	(2) Purchased June	(3) Purchased July	(4) Purchased August	(5) Purchased September
Proportion of barley	-0.248	-0.477	-1.086***	-1.250**	1.770**
	(0.312)	(0.706)	(0.326)	(0.516)	(0.801)
Proportion of wheat	0.142	0.190	-0.312*	0.009	-0.101
	(0.101)	(0.180)	(0.179)	(0.186)	(0.189)
Proportion of maize	-0.111	0.239	-0.283	-0.003	-0.193
	(0.139)	(0.230)	(0.175)	(0.258)	(0.223)
Proportion of land not lem	0.222***	0.195*	0.007	-0.152	-0.081
	(0.042)	(0.098)	(0.084)	(0.093)	(0.079)
Undertakes soil conservation	-0.038	-0.024	-0.072	-0.238***	0.197**
	(0.044)	(0.091)	(0.081)	(0.067)	(0.095)
Number of extension visits	0.003	-0.010	-0.004	0.002	0.019
	(0.005)	(0.013)	(0.009)	(0.014)	(0.013)
Uses DAP	-0.089	0.222	0.061	0.199	-0.299**
	(0.080)	(0.153)	(0.102)	(0.209)	(0.124)
Uses urea	0.061	-0.380***	0.060	0.018	0.225***
	(0.055)	(0.128)	(0.109)	(0.181)	(0.063)
Sample	full	insurance purchasers	insurance purchasers	insurance purchasers	insurance purchasers
Fixed effects	district	district	district	district	district
Observations	475	118	118	118	118
Adjusted R-squared	0.039	0.056	0.015	0.032	0.108

Notes: * Indicates significant at 10%, ** at 5% and *** and 1% levels of significance.

Table 14: Security choices in 2010 (SUR estimation)

	Purchased June	Purchased July	Purchased August	Purchased September
Proportion of barley	-0.477	-1.086	-1.250	1.770**
	(0.942)	(0.743)	(0.917)	(0.844)
Proportion of wheat	0.190	-0.312*	0.009	-0.101
	(0.210)	(0.166)	(0.205)	(0.188)
Proportion of maize	0.239	-0.283	-0.003	-0.193
	(0.239)	(0.188)	(0.232)	(0.214)
Proportion of land not lem	0.195*	0.007	-0.152	-0.081
	(0.110)	(0.086)	(0.107)	(0.098)
Undertakes soil conservation	-0.024	-0.072	-0.238**	0.197**
	(0.098)	(0.078)	(0.096)	(0.088)
Number of extension visits	-0.010	-0.004	0.002	0.019*
	(0.011)	(0.009)	(0.011)	(0.010)
Uses DAP	0.222	0.061	0.199	-0.299*
	(0.175)	(0.138)	(0.170)	(0.157)
Uses urea	-0.380***	0.060	0.018	0.225*
	(0.131)	(0.103)	(0.127)	(0.117)
Sample	insurance purchasers	insurance purchasers	insurance purchasers	insurance purchasers
Fixed effects	district	district	district	district
Observations	118	118	118	118
Adjusted R-squared	0.136	0.099	0.115	0.184