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Agricultural Decisions after Relaxing Credit and Risk Constraints*

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Abstract

The investment decisions of small-scale farmers in developing countries are conditioned by their financial environment. Binding credit market constraints and incomplete insurance can reduce investment in activities with high expected profits. We conducted several experiments in northern Ghana in which farmers were randomly assigned to receive cash grants, grants of or opportunities to purchase rainfall index insurance, or a combination of the two. Demand for index insurance is strong, and insurance leads to significantly larger agricultural investment and riskier production choices in agriculture. The salient constraint to farmer investment is uninsured risk: when provided with insurance against the primary catastrophic risk they face, farmers are able to find resources to increase expenditure on their farms. Demand for insurance in subsequent years is strongly increasing in a farmer's own receipt of insurance payouts, and with the receipt of payouts by others in the farmer's social network. Both investment patterns and the demand for index insurance are consistent with the presence of important basis risk associated with the index insurance, and with imperfect trust that promised payouts will be delivered.

Keywords: agriculture, insurance markets, credit markets, risk, underinvestment, misallocation

JEL: C93, D24, D92, G22, O12, O13, O16, Q12, Q14

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1. Introduction

Economic theory tells us that in long run equilibrium, all firms should operate with the same marginal product of labor and capital. Yet this is not what we observe in many markets. In manufacturing, misallocations of input intensity have been shown to be a major source of low total factor productivity (Hsieh and Klenow, 2009).

In agriculture, the predominant source of income for most individuals in developing countries (e.g., 60% of Ghanaians are farmers (Ghana Statistical Service, 2008)), we also observe tremendous heterogeneity in input intensity and output per acre. Capital and risk constraints may be key impediments to investment for smallholder farmers in Ghana. Broad comparisons across countries suggest a pattern of underinvestment for Ghana as a whole. For instance, cereal yields in Ghana increased from about 0.82 tons per hectare in 1961 to about 1.46 tons per hectare in 2005, as compared to increases in South Asia from 1.02 tons per hectare to 2.48 tons per hectare over the same period (WDI 2007). These trends mimic similar trends in investment: fertilizer use in Ghana increased from about 0.42kg/ha to 7.42kg/ha between 1961 and 2002, whereas South Asia fertilizer use increased from about 2.55kg/ha to about 104.17kg/ha. This is just one input but still a reflection of both the low level and growth of input use in Ghana. Similar patterns abound throughout sub-Saharan Africa.

This stylized fact has motivated many donors and policymakers to implement agriculture interventions in sub-Saharan Africa over the last half century. Many of these programs have tried to encourage the intensified use of inputs such as hybrid seeds and fertilizers, for which there is evidence of high expected returns. Experiments on farmers' plots across 12 districts of northern Ghana in 2010 with inorganic fertilizer in northern Ghana showed for an additional expenditure of $60 per acre (inclusive of the additional cost of labor), fertilizer use generates $215 of additional output per acre (Fosu and Dittoh, 2011). Yet the median farmer in northern Ghana uses no chemical inputs.[1] In focus group interviews regarding decisions on intensified input use, farmers commonly report "lack of money" or concerns regarding the high risk from weather and disease as key obstacles deterring investment.

The welfare gains from solving the risk problem could be huge, for three reasons. First, if risk is discouraging investment (e.g., see Carter and Barrett, 2006; Christiansen and Dercon 2010, JDE forthcoming; Rosenzweig and Binswanger, 1993), and marginal return on investments are high, the returns to removing risk could be high. Existing evidence from fertilizer in northern Ghana suggests that these returns are indeed high.[2] Second, agriculture in northern Ghana is almost exclusively rain-fed. Thus weather risk is significant and index insurance on rainfall has promise (and also avoids adverse selection and moral hazard problems with crop insurance). Third, we have strong evidence that rainfall shocks translate directly to consumption fluctuations (Kazianga and Udry, 2006). Thus mitigating the risks from rainfall should lead to not just higher yields but also smoother consumption.

To understand how capital and risk interact, and under what circumstances lead to underinvestment, we experimentally manipulate the financial environment in which farmers in northern

[1] This fact is derived from the control group of farmers in the first year of our survey, described in section 3 below.
[2] See also Fafchamps et al. (2011), Udry and Anagol (2006).

Ghana make investment decisions. We do so by providing farmers with cash grants, grants or access to purchase rainfall index insurance or both. The experiments are motivated by a simple model which starts with perfect capital and perfect insurance markets, and then shuts down each. Farm investment is lower than in the fully efficient allocation if either market is missing (and land markets are also shut down, given the restrictions of the land tenure system in northern Ghana). If credit constraints are binding, then provision of cash grants increases investment, but the provision of grants of insurance reduces investment. In contrast, when insurance markets are incomplete, provision of cash grants has a minimal impact on investment, but investment responds positively to the receipt of an insurance grant.

To test these predictions, we turn to a three-year multi-stage randomized trial.[3] In year one, we conducted two experiments. The first is a 2x2 experiment: maize farmers either received (a) a cash grant or no cash grant, and (b) a rainfall insurance grant or no rainfall insurance grant. In year two, we conducted another cash grant experiment, but only offered rainfall insurance for sale at randomly-varied prices ranging from one eighth of actuarially fair to market price (i.e., actuarially far plus a market premium to cover servicing costs) rather than giving some out for free as in year one. In year three, we did not conduct another cash grant experiment, but the insurance pricing experiment continued.

Four elements distinguish our data and experiments: (1) the cash grant experiment to measure the effect of capital constraints on investment and agricultural income (most of the existing complementary research is on the insurance component), (2) the provision of free insurance, in order to observe investment effects on a full population rather than just those willing to buy (a notable complementary study is Cole, Gine and Vickrey, 2011, who provide grants of free insurance to farmers in India), (3) multi-year setup, and (4) a complete demand curve, from nominally positive prices (8% of actuarially fair) all the way to approximate market prices (i.e., actuarially fair plus a 50% premium to cover servicing costs). In the Discussion section of this paper we relate our results to the complementary literature on risk and capital capitals for agriculture.

We find strong responses of agricultural investment to the rainfall insurance grant, but relatively small effects of the cash grants. The salient constraint to farmer investment is uninsured risk: when provided with insurance against the primary catastrophic risk they face, farmers are able to find resources to increase expenditure on their farms. At the actuarially fair price, 40 to 50 percent of farmers demand index insurance, and they purchase coverage for more than 60 percent of their cultivated acreage. Patterns of insurance demand are consistent with farmers being conscious of the important degree of basis risk associated with the index insurance product. Farmers do not seem to have complete trust that payouts will be made when rainfall trigger events occur, so the demand for index insurance is very sensitive to the experience of the farmer and others in his social network with the insurance product. Demand increases after either the farmer or others in his network receive an insurance payout, and demand is lower if a farmer was previously insured and the rainfall was good, thus no payout was made.

[3] Conducted as a “natural field experiment” in the sense that all grants and insurance offered were done so through an NGO, and although individuals obviously knew that researchers were conducting surveys, the grants and insurance were presented as those of an NGO, not researchers.

In the next section, we provide a simple model of investment in a set of different financial environments. Section 3 describes the empirical setting, the experimental interventions, and the data collection process. Section 4 provides the key results on the effects of cash and insurance grants on farm investment. Given these results, section 5 provides a model of the demand for insurance and agricultural investment when farmers do not face binding credit constraints. Section 6 provides results on the demand for index insurance, characterizes patterns of investment given the availability of index insurance at randomized prices, and explores the effects of social interactions on insurance demand. Section 7 discusses the implications of our results in the context of the literature, and Section 8 concludes.

2. Investment and the Financial Environment

In an environment with well-functioning markets, including markets for insurance and capital, the standard neoclassical separation between production and consumption would hold and farmers' input choices on a particular plot would be independent of their wealth and their preferences. Investment in inputs would maximize the present discounted value of the (state-contingent) profits generated by those investments. Where insurance markets are imperfect or absent, or credit constraints bind, separation no longer holds, and the randomized provision of capital grants or insurance that pays off in certain states may influence farmers' investment choices. The purpose of this section is to provide a simple model that permits us to use the investment response to capital grants and/or the provision of insurance to draw conclusions about the financial environment farmers face.

A minimal model sufficient for this purpose includes 2 periods, production, risk, and the appropriate financial markets. Preferences over consumption in the first period (c) and in the various states of the second period (c_s) are

(1) $$u(c) + \beta \sum_{s \in S} \pi_s u(c_s)$$

Start, naturally enough, with an environment with a perfect credit market and complete informal risk-pooling. The household (with exogenous cash on hand *Y*) has access to a market on which it can buy (or sell) a risk free asset (*a*) which earns (or pays) interest *R* $(= \frac{1}{\beta}$, to simplify notation later). The household is also a member of an informal risk sharing group which permits the efficient *ex*-post pooling of all risk. This informal risk sharing operates such that every household consumes the expected value of its second period consumption in any realized second period state. The farmer has a production technology that provides second period output equal to $f_s(x)$ in state *s* after inputs *x* are committed in the first period. In anticipation of our two-pronged intervention, let *k* denote a cash grant provided to the farmer in the first period, and k_s be a state-contingent payout promised if *s* occurs in the second period. *k* and k_s correspond to our experimental interventions providing grants of, respectively, capital and rainfall index insurance. The household maximizes (1) subject to

$$
\begin{aligned}
(2) \qquad & c = Y - x - a + k \\
& c_s = \bar{c} = \sum_{s \in S} \pi_s \left(f_s(x) + Ra + k_s \right) \\
& x \geq 0.
\end{aligned}
$$

We assume that the risk pooling group is sufficiently diverse that there is no aggregate risk. This extreme assumption serves to focus on the implications of binding credit constraints in the absence of any risk-based motivation for moving resources across periods. The household chooses a such that

(3) $$u'(c) = R\beta u'(\bar{c})$$

and farm investment satisfies

(4) $$1 = R\sum_s \frac{\partial f_s(x)}{\partial x}.$$

With complete credit markets and full risk-pooling, farm investment is independent of resources (Y) and preferences, as we expect. Neither a capital grant nor an insurance policy has any influence on farm investment:

(5) $$\frac{dx}{dk} = \frac{dx}{dk_s} = 0.$$

We now introduce, in turn, capital constraints and incomplete insurance markets. To simplify some of the notation which follows, we let $S = \{L, H\}$ with $f_L(x) < f_H(x)$. We also assume that the marginal product of inputs (*x*) is lower in L than in H; this of course need not be the case and is a substantive assumption. It corresponds to farmer accounts of their practices and understanding in northern Ghana.[4] To simplify some of the expressions below, we'll make the extreme assumption that the marginal return on inputs is zero in the low state but this is not essential for any of our results.

2.1 Capital Constraints

Suppose that borrowing is not possible, so to (2) we add the constraint that $a \geq 0$. We will consider situations in which this constraint binds. Informal consumption pooling remains complete, so every household consumes the expected value of its consumption in any state. With $a \geq 0$ binding the first order conditions become

(6) $$u'(c) > \beta r u'(\bar{c})$$

and

(7) $$u'(c) = \beta u'(\bar{c}) \pi_H \frac{\partial f_H(x)}{\partial x}.$$

[4] There is agronomic evidence as well. See Amujoyegbe et al. (2007).

The implicit function theorem immediately implies

(8) $$\frac{dx}{dk} > 0 > \frac{dx}{dk_L}.$$

The capital grant reduces the shadow price of the binding borrowing constraint, raising the relative value of consumption in the future and therefore inducing higher investment in x. In contrast, the promise of future resources, even in the bad state L, increases that shadow price and lowers the relative value of consumption in the future. Hence investment in x falls with promised contingent payments.

2.2 Imperfect Insurance

In the extreme, there is no informal risk pooling, so $c_s = f_s(x) + Ra + k_s$. The household chooses x and such that

(9) $$R\left[\frac{\pi_L}{\pi_H}\frac{u'(c_L)}{u'(c_H)} + 1\right] = \frac{\partial f_H(x)}{\partial x}$$

and

(9) $$u'(c) = \pi_L u'(c_L) + \pi_H u'(c_H).$$

Let $\{a^0, x^0\}$ solve (9) and (9) for k=0. If u(.) is CARA, then $\{a^1, x^0\}$ solves (9) and (9) for $k > 0$ (with $a^1 > a^0$) because

$$c_H - c_L = f_H(x^0) - k_L.$$

In contrast, increases in promised payouts in the bad state reduce the LHS of (9). Therefore, with CARA preferences, the absence of informal insurance implies that $0 = \frac{dx}{dk} < \frac{dx}{dk_L}$. The extreme conclusion that $\frac{dx}{dk} = 0$ relies on the CARA assumption. For the more reasonable case of decreasing absolute risk aversion, $\{a^1, x^1\}$ with $x^1 > x^0$ solves (9) and (9) for $k > 0$ because the absolute degree of risk aversion falls as c_L increases (and c_L increases with a^1). Thus, with imperfect insurance and decreasing absolute risk aversion we have

(9) $$\frac{dx}{dk}, \frac{dx}{dk_L} > 0.$$

Different mechanisms underlie the positive responses of risky investment in agriculture in response to the cash grant and the grant of index insurance. The cash grant increases cash on hand, saving in the safe asset and thus consumption in either state of the second period. With decreasing absolute risk aversion, (9) now implies more investment in the risky asset. Index insurance directly increases consumption in the low state of period 2, hence (9) implies greater investment in the risky asset.

2.3 Capital Constraints and Imperfect Insurance

With $a \geq 0$ binding, (7) remains a first order condition, and since a=0, $c = Y - x + k$ and $c_s = f_s(x) + k_s$. The implicit function theorem implies

(10) $$\frac{dx}{dk} > 0 \geq \frac{dx}{dk_s}.$$

To summarize, if farmers have access to complete risk pooling and capital markets, investment is invariant to both capital grants and the provision of free insurance. With binding credit constraints (either with or without complete insurance markets), investment rises with a capital grant and falls when insurance is provided. When credit constraints are not binding but insurance is imperfect, investment rises with the provision of insurance or a capital grant.

3. The Setting, the Interventions and Data Collection

3.1 Year One: Sample Frame and Randomization for Grant Experiment

In order to have a rich set of background data on individuals and a representative sample frame, we used the Ghana Living Standards Survey 5 Plus (GLSS5+) survey data to form the initial sample frame. The GLSS5+ was conducted from April to September 2008 by the Institute of Statistical, Social and Economic Research (ISSER) at the University of Ghana – Legon in collaboration with the Ghana Statistical Service. The GLSS5+ was a clustered random sample, with households randomly chosen based on a census of selected enumeration areas in the 23 Millenium Development Authority (MiDA) districts[5]. From the GLSS5+ sample frame, we then selected communities in northern Ghana in which maize farming was dominant, and then within each community, selected the households with some maize farming, but no more than 15 acres of land. Within each household, we identified the key decisionmaker for farming decisions on the main household plot, which was typically the male head of household (except in the case of widows). Our sample frame is over 95% male as a result. This yielded a sample frame of 502 households. We refer to this as Sample Frame 1, and it is used for the Grant Experiment. (Appendix Table 1 provides an overview of our sample frames, survey completion rates, and observations used for each table in the analysis.)

We randomly assigned the 502 households to one of four cells: 117 to cash grant, 135 to insurance grant, 95 to both cash grant and insurance grant, or 155 to control (neither cash grant nor insurance

[5] Ghana has 170 districts in total, twenty of which are located in the Northern Region. MiDA is the Ghanaian government entity created to lead the programs under the compact between the US Government Millennium Challenge Corporation (MCC) and the Ghanaian government. Although the sample frame for this study was generated from the GLSS5+, the interventions described here were independent of MiDA and MCC.

grant).[6] The unit of randomization was the household, and the randomization was conducted privately, stratified by community. We did not have the GLSS5+ data prior to the randomization, and thus were not able to verify *ex ante* the orthogonality between assignment to treatment and other observables. When cash and rainfall insurance grants were announced to farmers, they were presented not as part of a randomized trial but rather as a service from a research partnership between IPA and the local nongovernmental organization Presbyterian Agricultural Services (PAS).[7]

Error! Reference source not found. shows summary statistics, mean comparisons of each treatment cell to the control, an F-test from individual regressions of each covariate on a set of three indicator variables for each treatment cell (Column 7), and an F-test from a regression of assignment to each treatment cell on the full set of covariates (bottom row). No covariates show any statistically significant differences across treatment assignment.

3.2 Year One: Insurance Grant Design

We designed the insurance grant in collaboration with the Ghanian Ministry of Food and Agriculture (MoFA), Savannah Agricultural Research Institute (SARI) and PAS, and secured permission from the Ghana National Insurance Commission to research takeup and effects of a non-commercial rainfall index insurance product designed to make farmers feel insured. We held focus groups with farmers to learn about their perception of key risks and about the types of rainfall outcomes likely to lead to catastrophically low yields. Whilst rainfall data for Ghana was available from 1960 onwards from the Ghana Meteorological Service (GMet), equivalent data was not available for crop yields, so we used ICRISAT yield data from Burkina Faso for baseline estimates of the impact of rainfall variation on crop output. Given the limitations of this historical data and the differences between Burkinabe and Ghanaian farming systems, our decision about the trigger rainfall amounts for insurance payouts was made largely on the basis of our qualitative discussions with our Ghanaian partners and farmers. The value of insurance payouts in case of catastrophically low yields was set to be equal to mean yields in

[6] Since the budget for this research included the cost of the intervention and since the size of the sample frame was not fixed, we optimized statistical power by increasing the size of the control group relative to the treatment groups. However, since the exact formula for optimal power depended not just on the relative cost but also on any change in variance, we did not solve this analytically but rather approximated.

[7] The script for the field officers for the insurance grant, for example, was as follows: “I am working for NGOs called Innovations for Poverty Action and Presbyterian Agriculture Services. We are trying to learn about maize farmers in the Northern Region, and in (Tamale Metropolitan / Savelugu-Nanton / West Mamprusi) district. As part of this research, you are invited to participate in a free rainfall protection plan called TAKAYUA Rainfall Insurance, which I would like to tell you about.” Control group households were informed that others in their community had received grants but that limited resources did not allow everyone to receive one, and that the selection was random and thus fair to everyone.

the GLSS5+. We also were concerned with product complexity and farmer understanding, and acknowledge that simplicity came at the expense of increased basis risk (see Hill and Robles (2010) for an analysis and innovative approach using laboratory experiments to assess farmer perception of basis risk and insurance fit). The trigger for payouts was determined based on the number of dry or wet days in a month (where either too much or too little rainfall triggered a payout). The payout amount was chosen in order to approximately cover 100% of a full loss, or roughly $145 per acre of maize grown.

We used five rainfall gauges in 2009. The mean distance from plots to the rain gauge ranged from 9.7km to 37.6km. Appendix Table 2 provides summary statistics on distance to farmer homesteads in our sample and rainfall for each gauge, and Figure 7 provides a map of the area and location of communities and rain gauges in the study.

Around March of 2009, we sent insurance marketers to those villages selected to receive the insurance offer, where a Ministry of Food and Agriculture-appointed farmer and PAS-employed field officer assisted us in identifying those farmers selected to receive the insurance offer. During these individual visits with selected farmers, marketers described the insurance policy in a clear and simple way, left a copy of the policy document with each farmer, and informed the farmer he would have approximately two weeks to decide whether to take up the offer. Marketers returned to each farmer two weeks after this visit and issued a certficate to those farmers agreeing to take up the product. In this case, where the product was offered at no cost, 100 percent of farmers took it up.

A total of 230 policies were issued to farmers free of cost in year one, covering a total of 1,159.5 acres, for an average of about five acres per farmer. We granted each farmer insurance coverage for the number of acres they reported farming maize in the GLSS5+. One payout was made to 171 farmers in July of 2009 at $85 per acre, or roughly 60 percent of estimated loss. The average payout was $350 per farmer, conditional on receiving a payout.[8] Payouts were made within two weeks of the rainfall shock that had triggered the payout, with the intention that the cashcould have been applied to investment in labor during harvest.

3.3 Year One: Cash Grant Design

For those in the cash grant treatment, we first announced the grant and explained it the same way as the insurance grant: as a collaboration between IPA and PAS to help smallholder farmers and learn more about farming in northern Ghana. We made three key design decisions concerning the cash grant

[8] In order to test an involuntary soft commitment to spend the insurance payouts on large indivisible investments, we also randomized the size of the bills in which the cash was delivered. The options were small bills (i.e., usable in their local community) or large bills (realistically not usable unless they travel to Tamale, the closest major city, and also where they typically would buy farm inputs in the following season). We do not report on the results from that sub-experiment in this paper.

treatment: the timing, the amount, and whether to transfer in-kind goods or cash. For the timing, we decided to individualize delivery of the grant based on the farmers' stated preferences and intentions about use of the grant. Thus if they reported it would all go to seed, they would receive the cash at time of planting, whereas if they reported half would go to seed and half to labor for harvest, half the cash would be delivered during the planting period and half at the harvest. Beyond timing the cash to coincide with their stated use, we did not do anything to impose compliance, i.e., we did not tell them they must use it for what they said, nor did we verify or tell them we would verify the purchases. Of course we cannot control what they thought, and how they thought their behaviors may influence future grants.

With regard to the amount of the grant, we decided to make it a fixed total amount per acre of land, despite the distributional consequence of this from a policy perspective, because our interest here is in studying returns to capital. We delivered $85 per acre (up to 15 acres) to 212 farmers selected to receive cash grants. We determined the amount by working with MoFA to determine the total cost of inputs and labor costs as per the MoFA recommended maize farming practices. Finally, we decided to give cash rather than in-kind. This was done in order to allow the farmers to use the resources in what they considered their highest return activities, regardless of what they initially said they would do with the funds. Due to budget constraints, we were unable to randomize the implementation of the grant in order to test out the various options on amount, timing and cash vs. in-kind delivery.

3.4 Year Two: Expanded Sample Frame for Insurance Product Pricing Experiment

For year two, we then expanded the sample frame in order to conduct an Insurance Product Pricing Experiment. The second year insurance coverage also was redesigned and renamed to *Takayua* (which means "umbrella" in the local Dagbani language), and calibrated to trigger per-acre payouts after seven or more consecutive "wet" days (over 1mm of rainfall) or after twelve or more consecutive "dry" days (1mm or less rainfall). Payouts under *Takayua* were promised to be delivered two weeks after the dry or wet spell had been broken.

The Insurance Product Pricing Experiment included the Grant Experiment sample frame from Year 1, as well as two new sample frames: new households drawn from the Grant Experiment communities (Sample Frame 2), and entirely new communities (Sample Frame 3). The price was randomized at the community level in order to facilitate communication and avoid confusion that would result from offering insurance at different price levels within a single community, but every community also had control group farmers without access to the insurance; this randomization is at the household level.

For Sample Frame 2, the expansion in communities already part of the Grant Experiment, we first conducted a census in order to select additional households for the sample. Using our census, we applied the same filter as in the Grant Experiment (maize farmers with fewer than 15 acres). This yielded

676 additional households. We then randomly assigned each community to be sold the insurance product at a price of either GHC 1 or GHC 4 ($1.30 or $5.25), and then randomly drew 867 of the 1,178 in Sample Frame 1 and 2 to be sold the insurance, with the remaining 311 being in a control group of individuals not offered the insurance.[9] Both prices represent considerable subsidies, as the actuarially fair price was about eight cedis ($10.50) per acre. Offers were made in November 2009, and we sold 402 out of 475 offered at 1 GHC, and 261 out of 392 offered at 4 GHC. Table 1 Columns 8-10 show the summary statistics along several baseline characteristics for this sample frame, and Column 11 presents results from an f-test for each covariate individually, and the bottom row shows an f-test for the correlation between all covariates and each treatment assignment individually. We are unable to reject that the covariates are uncorrelated with assignment to treatment in 6 out of 8 of the baseline measures. The two that reject are total acreage and total costs. For total acreage, the control group mean is 6.29 acres, the 1 GhC group is 6.26 acres, and the 4 GhC group is 5.03 acres (thus generating the statistically significant difference). For total costs, given the smaller acreage, the 4 GhC group is also smaller (control group mean is 1430, 1 GhC group is 1320, and 4 GhC group is 1118). This possible imbalance, if not mere measurement error, would lead to a downward bias in our estimates on investment impact. The three tests for all covariates aggregately (bottom row of table) all fail to reject the null hypothesis of no correlation (p-values of 0.12, 0.16 and 0.69 for assignment to 1 GhC, 4 GhC and control group, respectively).

For Sample Frame 3, we expanded to new communities, and used this sample frame to test actuarially fair and market-based prices for the same insurance product. First we randomly selected 12 new communities from maps of the areas that delineated all communities within 30 kilometers of one of the rain gauges. We then completed a census in each community and filtered the sample using the same criteria as the Grant Experiment (maize farmers with fewer than 15 acres). We drew 228 households (19 per community) into the sample frame. We then randomly assigned each community to receive insurance marketing at either the estimated actuarially fair price (GHC 8 or 9.5 ($10.50 or $12.50), depending on the rain gauge), or the estimated price in a competitive market (GHC 12 or 14 ($15.85 or $18.50), depending on the rain gauge). Offering the insurance product at several prices, including at the estimated actuarially fair and competitive market prices, allowed us to measure demand for the product at different prices and to further refine a demand curve for rainfall index insurance in the region. Offers were made in March 2010, and we sold 17 out of 38 policies offered at 8 GHC, 31 out of 76 policies offered at 9.5 GHC, 7 out of 38 policies offered at 12 GHC and 6 out of 76 policies offered at 14 GHC.

For both sample frames, each farmer who purchased insurance was visited four times as part of the marketing. During the first visit, a marketer educated individual respondents about the *Takayua* product

[9] Throughout the paper, we use the PPP exchange rate of 0.6953 Ghana Cedi to US$1 for 2009, 0.7574 for 2010, and 0.7983 for 2011 (World Bank, 2011).

and its price. During the second visit, a marketer returned to sign contracts with and collect premiums from respondents. During the third visit, a marketer issued a physical policyholder certificate, including details on the policyholder and acreage covered, to each policyholder. During the fourth visit, an auditor from IPA verified understanding of the terms and conditions of *Takayua* with roughly 10 percent of farmers who had chosen to take up the product.

To better understand farmers' comprehension of the policies and learn about their perceptions of basis risk, we conducted a post-harvest survey with 672 of 729 *Takayua* policyholders following the year two harvest in December 2010. The survey revealed that 41.3 percent of farmers who received one payout found it sufficient to cover damages sustained, but that 97.9 percent of the treatment group indicated willingness to purchase the product again for the 2011 farming season.

3.5 Year One Followup Survey \ Year Two Baseline Survey

In January through March 2010, we attempted to survey 1,178 farmers, the union of the 502 households in Sample Frame 1 (the Grant Experiment) and 676 households in Sample Frame 2 (the year two Insurance Product Pricing Experiment farmers that were from existing communities).[10] We completed 1,087 of 1,178 surveys, for an overall response rate of 92 percent.[11]

3.6 Year Two: Cash Grant Experiment

In the year two Cash Grant Experiment conducted between May and June 2010, we repeated the cash grant to a newly randomized treatment group of 363 (out of 676) farmers from Sample Frame 2 (i.e., thus there was no overlap with those in the year one capital grant experiment). The cash grant was $462 per household, regardless of acreage, and the entire amount was given to the farmers at a single time.

3.7 Year Two: Insurance Payouts

Two of five rainfall stations triggered payouts totaling just over $100,000 in 2010. The Tamale (Pong) station measured eight consecutive wet days in late August triggering a payout of $26 per acre to 125 individual farmers with 785 acres. The second payout was made when the Walewale station recorded 11 consecutive wet days in late September triggering a payout of $66 per acre to 225 individual farmers

[10] The product pricing experiment in new communities took place immediately after this survey was completed, thus Sample Frame 3 is included in the 2011 followup survey but not this one. Four farmers were dropped between years due to administrative error.

[11] The comprehensive survey was conducted using netbooks. This survey included: household socioeconomic indicators (including education, health, waged labor, and formal employment), plot-level farming questions (including land tenure, seeds, chemical inputs, agricultural labor, harvest, crop sales and storage), livestock, fishing, agricultural processing, household assets, expenditures, consumption, social networks, insurance knowledge, risk perceptions and finance (including borrowing, lending, savings, other income, and transfers).

with 1,254 acres. These payouts were made within two weeks of the trigger event, in fulfillment of the contract terms established between IPA and *Takayua* policyholders.

3.8 Year Two: Follow-up Survey

In February and March 2011, we conducted a second follow-up survey targeting 1,406 households, the union of Sample Frame 1 (the year one Grant Experiment), Sample Frame 2 (the year one Insurance Product Pricing experiment on households from villages in the Grant Experiment) and Sample Frame 3 (the year one Insurance Product Pricing experiment on households from new villages, i.e., no overlap with the Grant Experiment). We reached 1,252 of the 1,406 households, for an overall response rate of 89 percent.

In order to ensure data quality, the instrument was programmed to ask for confirmation of and updates on last year's data, through "preloading" reported data about household members, plots, employment, assets, livestock and loans. The survey also asked for new data on areas including harvests, crop storage and sales, chemical use, seed sources, ploughing, livestock, income, expenditures, assets, loans, agricultural processing, education, health, household enterprise and formal employment.

3.9 Year Three: Commercial Product and Pricing Experiment

In May 2011, we negotiated a partnership with the Ghana Agricultural Insurance Programme (GAIP) to market GAIP's commercial drought-indexed insurance product, a product reinsured by Swiss Re and endorsed officially by the National Insurance Commission. Due to the increased complexity of the commercial product (compared to the original non-commercial product from years one and two), individual marketing scripts and protocols emphasized transparency about the product, named *Sanzali*, the Dagbani word for "drought". Sanzali was divided into three stages based on the maize plant's growth stage, and each stage included one or two types of drought triggers (cumulative rainfall levels over ten day periods, or consecutive dry days). Because the *Sanzali* product was significantly more conservative than the *Takayua* product, the marketing session this year included an in-depth comparison of terms and historical payouts. The *Sanzali* product was offered at an actuarially fair price of $7.90 per acre, as well as a subsidized price of $4.00 per acre and a market price of $11.90 per acre. The pricing assignments were randomized by community, with 23 communities (31.9 percent) in the market price cell, 23 communities (31.9 percent) in the actuarially fair and 26 communities (36.2 percent) in the subsdized price cell.

The same farmers from the year two pricing experiment were included in this year three pricing experiment. We offered insurance to 1,095 farmers and sold a total of 655 policies (59.8%). As with year two, each farmer was visited up to four times. Demand was 63.9% at the subsidized $4.00 per acre price, 55.6% at the actuarially fair GHC $7.90 per acre price, and 40.0% at the market price GHC $11.90 per acre.

As with the second year, three to seven days after the marketing visit, IPA staff conducted audit visits with ten percent of the insurance group to test their comprehension of the product. Audit reports confirm that farmers had a clear understanding of the product, including complex ideas such as cumulative rainfall per dekad. IPA also conducted informal interviews to gain insight into how smallholders financed their insurance purchase, finding that smallholders made their purchases through informal loans, produce sales, gifts, or small ruminant sales.

3.10 Year Three: Insurance Payout

The insurance product in year three (2011) did not trigger any payouts.[12]

4. Capital Grants, Insurance and Investment

Figures 1-4 summarize the consequences for farm investment of the randomized provision of either capital grants, rainfall index insurance, or both. The first panel of Figure 1 shows that the CDF of total expenditures on the farms of households who received free insurance is strongly shifted to the right of that of control group farmers. The strongest effects are in the left tail of the distribution of farm expenditures: the 25th percentile increases by about $570, from a base of $875. The second panel indicates that there may be a difference between the control group and the capital grant group in the left tail: the 25th percentile of the grant group is about $205 higher than that of the control group, but the difference is eliminated from the median onward. The final panel shows that the CDF of total expenditures for the group that received both the capital grant and insurance is also shifted to the right of that of the control group; but there is little substantive difference between the CDFs of the group that received only insurance (panel 1) and the group that received both insurance and capital (panel 3).

The effects of capital grants and insurance on total expenditure are not those that one would expect to see for farmers facing binding credit constraints. Farmers in the insurance group were

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[12] Although not reported in this paper, we conducted a notification experiment after the realization that there would be no payout. We were concerned that silence may lead to longer term mistrust. Thus in December 2011, we conducted a notification experiment and harvest survey with the 572 *Sanzali* policyholders. In the notification experiment, some policyholders were notified individually and otherswere notified as part of a group about rainfall measurements recorded at their nearest rain gauge and about insurance outcomes. The notification experiment served two purposes: (1) to respond to requests made by policyholders during the 2010 harvest survey and 2011 insurance marketing to provide information about insurance outcomes at the end of each coverage period, and therefore to build upon established trust between marketers and communities, and (2) to test group education rather than individual education to ensure the same treatment effect could be generated at lower cost, and therefore to inform planning for community-level marketing activities in 2012.

promised future resources in certain states of the world, and given nothing up front. With binding credit constraints, this would have induced farmers to reduce investment on farming activities; instead, we see a dramatic increase.

Figure 2 Panel 1 documents a similar increase by the insurance group in expenditures on farm chemicals, largely fertilizer. Figure 2 Panel 2 shows that the capital grant group also strongly increased their expenditure on chemicals, as did the group that received both capital grants and insurance.

In Figure 3, we see that insurance also has a positive effect on the acres cultivated by farmers (the step pattern is driven by clustering at unit values of reported cultivated acres), but that there is no difference between the CDFs of area cultivated by the control and capital grant groups. Harvests may be higher for the group that received insurance than for the control group (Figure 4), but the difference is relatively small (about \$120 at the 25th percentile, off a control group base of \$475). However, the group that received both insurance and capital does have a CDF of harvest values that is distinctly shifted to the right of that of the control group (\$190 at the 25th percentile). We will discuss this pattern further below, where we argue that it and other evidence may reflect the salience of both basis risk and the impact of the capital grants on the expectations of policyholders that insurance payouts will be made when trigger events occur.

The index insurance product we designed had the feature that payouts would be made quickly – within a week – of the realization of a trigger. Thus some payouts happened mid-season, not post-harvest. This leads to the natural question as to whether the observed investment responses could simply reflect the insurance payouts, and not a behavioral response upon receiving the insurance contract? Figure 3 is key to examining this issue, because cultivated area is determined during the plot preparation stage of the farming season, before any insurance payouts could be made. Thus although we cannot rule out *any* later investments happening with the insurance proceeds from negative shocks, we do clearly observe some behavioral response prior to any cash infusion.

5. Modeling the Demand for Insurance and Investment

We focus on an environment in which farmers are not confronted with binding credit constraints, but in which they do not have access to complete informal insurance mechanisms. We continue to consider a world with two states and examine the demand for rainfall index insurance at price *p* that pays off in state *L*. The household's budget constraints are now

(11) $$c = Y - a - x - pI$$

(12) $$c_H = f_H(x) + Ra$$

(13) $$c_L = f_L(x) + Ra + I$$

In addition to non-negativity constraints on *c*, c_H, c_L and x, short sales of *I* are not feasible:

(14) $$I \geq 0.$$

If the non-negativity constraints are not binding, the first order conditions for I, a, and x are

(15)
$$\frac{u'(c)}{u'(c_L)} = \frac{\beta \pi_L}{p}$$

(16)
$$u'(c) = \pi_H u'(c_H) + \pi_L u'(c_L)$$

(17)
$$u'(c) = \beta \pi_H u'(c_H) \frac{\partial f_H(x)}{\partial x}.$$

If $p = \frac{\pi_L}{R}$ then the insurance is actuarially fair, (14) will not bind and we have the familiar result that $c = c_L = c_H$. In such a case, consumers demand full insurance and the expected return to investment in the risky agricultural activity is equal to R. Index insurance, however, unless subsidized, is rarely actuarially fair but rather sells at a premium to cover the transaction and operations costs for the company if a competitive market, and also economic profits if non-competitive. When $p > \frac{\pi_L}{R}$, i.e., above actuarially fair, households demand less than full insurance and $c_L < c < c_H$. Therefore,

$$R < \pi_H \frac{\partial f_H(x)}{\partial x}.$$

Farm investment is lower than it would be in the case of actuarially fair insurance, because the investment pays off more in the state in which resources are less valuable. However, as long as insurance demand is positive, there is a separation result. Combining (15)-(17) we have

(18)
$$\frac{R}{1-Rp} = \frac{\partial f_H(x)}{\partial x}.$$

Despite the fact that there is not full insurance and households are risk averse, production decisions are separable from preferences, wealth and from the riskiness of the farmer's land. There is of course a $p^* > \frac{\pi_L}{R}$ such that insurance demand is zero and (14) binds for all $p \geq p^*$. in this case, the household equalizes the marginal return to investing in *x* and in *a:*

$$\pi_H \frac{\partial f_H(x)}{\partial x} u'(c_H) = R\left(\pi_H u'(c_H) + \pi_L u'(c_L)\right)$$

and the optimal choice of *x* depends upon household preferences and wealth. Separation of production decisions occurs only for households that purchase insurance.

5.1 Selection and Heterogeneous Treatment Effects

Consider a set of farmers characterized by varying coefficients of absolute risk aversion θ_i but otherwise identical. Let $x_i(p)$ and $I_i(p)$ denote the farm investment and insurance demand of type *i* at price *p*,respectively, and $x_i(a)$ be the farm investment by type *i* without access to insurance. The treatment effect of access to insurance at price *p* for type *i* is

(19) $$T_i(p) = x_i(p) - x_i(a).$$

From (18), $T_i(p_1) \geq T_i(p_2)$ for $p_1 < p_2$, and the inequality is strict if $I_i(p_1) > 0$. That is, the treatment effect on farm investment by a specific farmer of making insurance available at a high price is (weakly) less than that of making insurance available at a lower price, although it is nonnegative at any price.

However, making insurance available at a higher price induces a different set of farmers to purchase insurance than making insurance available at a lower price, and the treatment effect at a given price varies across these different types.From (15)-(17) we have

(20) $$\frac{u'(c_H)}{u'(c_L)} = e^{-\theta[f_H(x)-(f_L-I)]} = \frac{\pi_L}{\pi_H}\frac{1-Rp}{Rp}.$$

If $\theta_1 > \theta_2$, and both types of farmers are purchasing insurance at price p, then $x_1(p) = x_2(p)$ and $I_2(p) > I_1(p)$. Unsurprisingly, the more risk averse farmer purchases more insurance at every price *p*. Since this holds at every price, the price at which (14) binds for type *1* is greater than that for type *2*: $p_1^* > p_2^*$.

Consider treatment effects at $p_L < p_2^* < p_1^*$; at this price both types of farmer demand insurance when it is available. Since $x_1(a) < x_2(a)$ and $x_1(p_L) = x_2(p_L)$, $T_1(p_L) > T_2(p_L)$. If the population of farmers consists of these two types, an empirical estimate of the treatment effect at the low price will lie in between, depending upon the population shares of the two types.

Suppose $p_2^* < p_H < p_1^*$, so that only type 1 purchases insurance. $T_1(p_H) < T_1(p_L)$, as argued above, the investment response of type *1* farmers is less if they gain access to insurance at a higher price. But this response may be greater than the response of type *2* farmers to insurance at a lower price. $T_1(p_H) > T_2(p_L)$ if

$$x_2(a) - x_1(a) > x_2(p_L) - x_1(p_H) = x_1(p_L) - x_1(p_H),$$

which for given θ_1, θ_2 will be satisfied for $p_H - p_L$ sufficiently small. In this case we have $T_2(p_L) < T_1(p_H) < T_1(p_L)$, and the LATE estimate of the treatment effect of availability of insurance at the low price can be higher or lower than the LATE estimate of the treatment effect of insurance at the high price. The selection effect of the higher price can offset its direct demand effect, so the net treatment effect of varying price is ambiguous.

We have illustrated this heterogeneity with respect to variation in risk aversion across farmers, but similar results based on analogous reasoning can be obtained for other dimensions of heterogeneity as discussed below.

5.2 Basis Risk

An essential aspect of any actual index insurance product is basis risk. Insurance payouts are not identical with the realization of bad states. We introduce basis risk by adding a state *N* in which there is no payout. We suppose that $f_N(x) = f_L(x)$; this is not necessary for the analysis but is convenient for reasons that will become apparent in the next subsection. Consumption in that state is

(21) $$c_N = f_N(x) + Ra.$$

Given our assumption on f_N, we have $c_L - c_N = I > 0$. If the insurance is actuarially fair, $c = c_L$. The choice of the safe asset is governed by

(22) $$u'(c) = \pi_H u'(c_H) + \pi_L u'(c_L) + (1 - \pi_H - \pi_L) u'(c_N).$$

If the insurance is actuarially fair, then, we have

$$c_H > c = c_L > c_N .$$

Farm investment satisfies

(23) $$\pi_H \frac{\partial f_H(x)}{\partial x} = \frac{Ru'(c)}{u'(c_H)} > R$$

and *x* is lower than when there is no basis risk.

With CARA preferences, investment remains invariant to capital grants even in the presence of basis risk. The FOC for *x*, *I* and *a* are (15), (22) and (17). Consider farmers *0* and *1* with $k^1 > k^0$. Then if x^0, I^0, a^0 satisfy the budget constraints ((11), (12), (13), (21)) and the FOC for farmer *0*, then $x^1 = x^0$, $I^1 = I^0$ and $a^1 = \frac{k^1 - k^0}{R - 1}$ are optimal for farmer *1*. With decreasing absolute risk aversion, as in section 2, *x* increases with capital grants.

5.3 Trust

The introduction of a new insurance product is associated with a problem of trust. Why should a farmer believe a financial institution that promises a contingent payout if state *L* occurs in the future? To consider this question, suppose state *N* is a state identical to state *L*, but in which the promised insurance payout is not made. $(1-\pi_H-\pi_L)$ is now a measure of *distrust* in the insurance. Holding constant π_H, an increase in π_L represents an increase in a farmer's trust that a payout will be made in a bad state. Consider a price such that insurance demand is positive. Since from (15)

(23) $$\frac{d\left(\frac{u'(c)}{u'(c_L)}\right)}{d\pi_L}=\frac{\beta}{p}>0,$$

(22) implies

$$\frac{d\left(\frac{u'(c)}{u'(c_H)}\right)}{d\pi_L}<0.$$

Hence, from (17),

(23) $$\frac{dx}{d\pi_L}>0.$$

At any price of insurance, and for any conventional risk averse preferences, an increase in the farmer's trust that payouts will be made increases investment. The increase in trust *a fortiori,* increases purchases of insurance: c_H-c_L declines as π_L increases, and $c_H-c_L=f_H(x)-f_L+I$. The demand for insurance increases more than $f_H(x)$ as π_L increases.

Farmers may have varying degrees of trust that the insurance will make payouts in bad states of nature. If this is so, then the analysis in section 5.1 regarding heterogeneous treatment effects applies in this dimension as well. Farmers with greater trust will experience larger treatment effects of access to insurance at any given price (by (23)). At higher insurance prices, farmers with less trust that payouts will be made will disproportionately drop out of the pool of insurance purchasers (from (23)). The qualitative process of selection is the same for heterogeneity in trust in the insurance product as we saw for risk aversion. In section 6.4, we examine two sources of information that might induce a change in π_L: one's own experience with the index insurance, and the experience of individuals in one's social network with the insurance.

6. The Demand for Index Insurance, Investment and Social Interactions

6.1 The Demand for Rainfall Index Insurance in Ghana

The random variation in the price at which farmers were eligible to purchase rainfall index insurance permits us to examine in a straightforward way the demand for this product. Figure 5 shows the fraction of farmers purchasing insurance as a function of the price of the insurance. The actuarially fair price of the insurance product was between 8 and 9.5 cedis per acre (depending upon the specific rainfall station). In contrast to Cole et al. (2010), demand did not drop off radically when a token price of 1 cedi per acre was charged; even at the actuarially fair price, 40 percent to 50 percent of farmers purchased insurance. Demand falls to 10% to 20% of farmers at higher rates of 12 to 14 cedis per acre. Again in contrast to Cole et al. (2010), farmers are purchasing more than token amounts of insurance. On average, farmers who purchased insurance (at a price greater than zero) purchased coverage for more than 60 percent of their acreage. Figure 6 shows the fraction of acreage for which insurance was purchased at every price (including 0 for those who did not purchase insurance).

Table 2, Column 1 is the regression analogue of Figure 5. The dependent variable is an indicator variable for obtaining insurance coverage. The regression includes all three years of data, and in addition to indicator variables for treatment status (the various prices and prices/capital grant combinations) includes indicator variables for year effects and year-sample stratification categories. The general pattern observed in Figure 5 is replicated.

There are two insurance prices (p=1 and p =4) at which some farmers received capital grants and others did not. At p=4, the quantity demanded is higher among those who received the capital grant (78% versus 70%, p-value from joint test of equality of coefficients at p=1 and p=4 = 0.01, reported at bottom of table). This contradicts the conclusion of section 5.2 above: with CARA preferences, insurance demand at a specific price should be independent of the capital grant. If farmers have decreasing absolute risk aversion (say, because they have CRRA preferences) then the demand for insurance at a fixed price should be *smaller* for those farmers who received the capital grants.

Several factors however could in a more encompassing theory lead to higher demand for those with the capital grant than for those without the capital grant. First, if the receipt of a capital grant increases recipient farmers' trust that payouts will be made on the index insurance when a trigger event occurs, then insurance demand will be higher at any price for those who receive a grant. Second, insurance demand may increase with the capital grant if there are unobserved informal insurance mechanisms that guarantee a minimum consumption level. This would work through a wealth effect from the cash grant: the cash grant reduces the likelihood that this limited liability feature of the consumption allocation comes into play, thus increasing the effective risk aversion of farmers who are recipients of the capital grants. However, in Table 2, Column 2 we show that the demand for insurance, conditional on the insurance price, is uncorrelated with baseline household non-land wealth. We divide our measure of wealth by 250 cedis so that wealth is measured in "capital grant units" to ease comparison across columns 1 and 2, and the result is a point estimate of 0.00 and a standard error of 0.001. We return to this combination of results – that insurance demand increases with the receipt of a capital grant, but is not correlated with household wealth -- in section 6.4. Third, although the grants had not been made at the time of insurance purchase, the expectation of the grant may have made individuals more likely to use available cash for the insurance, rather than investment in the farm. This seems implausible to explain the result, however, given the low cost of insurance (1 or 4 GHC per acre) relative to the investment costs. Finally, an experimenter or "NGO" effect may have occurred, in which individuals who receive the grant were more likely to buy the insurance in order to reciprocate to the NGO for giving them the capital grant.

In columns 3 and 4 of Table 2 we limit the sample to the first two years of the data because those are the years for which we currently have information on farmer investment. In column 1, 2 and 3, the dependent variable is equal to 1 if farmer *i* has insurance in year t and 0 otherwise. In column 4, the dependent variable is an indicator variable that the farmer has both insurance and a capital grant in year t. Columns 3 and 4, therefore, report the first stage estimates for the instrumental variables regressions we implement below. The instrumental variable specification requires one key assumption regarding the exclusion restriction: that the mere offer of insurance did not constitute a conveyance of information, such that even those who did not accept the offer of insurance shifted their existing beliefs regarding the marginal returns to agricultural investment. As the marketing insurance did not get delivered alongside any technical assistance on farming, we believe this is a reasonable assumption to make.

6.2 Investment and Insurance

Table 3 presents estimates of the regression analogues of Figures 1-4, using the two years of data for which we have information on farmer investments. The regressions are

(24) $$Y_{it} = \alpha_0 + \alpha_I I_{it} + \alpha_B B_{it} + \alpha_K K_{it} + \alpha X_{it} + \varepsilon_{it}$$

where I_{it} is an indicator variable that farmer i has rainfall index insurance in year t, B_{it} is an indicator that farmer i has both rainfall index insurance and a capital grant in year t, and K_{it} is an indicator that the farmer has a capital grant only in year t. X_{it} is a vector which includes indicator variables for the second year, the sampling strata, and interactions of these. I_{it} and B_{it}, of course, are endogenous because they depend on farmer demand for insurance. These are instrumented using the randomized prices of insurance, interacted with an indicator of receiving a capital grant, as shown in 2.

Farmers with insurance invest more in cultivation. Total cultivation expenditure, inclusive of the value of household and exchange labor (valued at community-gender-season specific wages), is $266 (se=134) higher for farmers with insurance than for farmers in the control group. Mean expenditure in the control group is $2058, so the magnitude of the increase associated with insurance is quite large. The point estimate of the additional investment associated with receiving a capital grant along with the insurance is positive but not statistically significantly different from zero ($72, se = 139). The point estimate of joint effect of insurance and the capital grant is to increase investment by $338 (p-value 0.02 reported in the final row of the table). The capital grant alone has no significant effect on investment ($2, se = 149). These results are consistent with those shown in Figure 1 and are inconsistent with the presence of binding credit constraints. Farmers with insurance are able to find the resources to increase investment in their farms.

Columns 2-4 of Table 3 show that the primary cash expenditures on cultivation are higher for insured farmers. Expenditure on chemicals (mostly fertilizer), land preparation (largely tractor rental) and hired labor are all higher for farmers who are insured. Similarly in column 6 we show that the area cultivated by farmers with insurance is higher. These are all large and statistically significant increases, relative to the means of these items for control group farmers. We do find one effect from the capital grant alone: farmers who receive a capital grant alone have higher expenditures on chemicals compared to control group farmers. We also find an additive effect, but just for chemical investments: those who receive the capital and insurance invest $66 (se = 16) more than those who receive just the insurance. These increases in expenditure on chemicals associated with the capital grant are consistent with the model in section 2.2 for farmers with decreasing absolute risk aversion, although the magnitudes are strikingly large. We return to these results in section 6.4.

In column 5, we see that there are no statistically significant changes in value of family labor (which we price at gender-community-season specific wages) among farmers who receive any of the treatments. The measurement of family labor used on farms remains a significant empirical challenge for an annual retrospective survey.

Column 7 reports that the total value of production may be higher for households with insurance, but the estimate is not statistically significant ($104, se = 82). The joint effect of insurance and a capital grant is large and significant ($233, p-value=0.01, from a control group mean of 1177). Even if statistically significant, the increase in the value of output is not sufficiently large to generate additional profits. In no group can we reject the hypothesis that the higher value of output after treatment is equal to the increase in total expenditure.

There is an important issue to keep in mind when interpreting results on farm profits (e.g., subtracting the effects in column 1 from those in column 7). The most important component of total costs is the value of household labor. But the market for hired labor is thin and it is not clear that this observed wage is the appropriate opportunity cost of family labor (similar results are found with respect to cows in India, where profits are positive only if family labor is valued at zero, see Anagol et al 2012). This may be the most important reason for the observation that profits are typically negative in this and similar data from rural west Africa (profits turn positive only at the 60^{th} percentile of realized profits in the control group when family labor valued at gender-community-season specific wages, whereas profits turn positive at the 15^{th} percentile of realized profits in the control group when family labor is valued at zero).

Next, in Table 4, we examine not just the level of investment (as we did in Table 3), but the riskiness of investment. We do this by using the same specification as in Table 3, but adding independent variables for total rain and the interaction of total rain with treatment assignment. A positive coefficient on the interaction term, when predicting harvest value, implies farmers made investments that were more sensitive to rainfall if they had insurance. Table 4 Column 8 shows that indeed this is the case: insurance alone at zero rainfall leads to -$1,069 (se=596) lower output, and for each millimeter of rainfall the output increases by $157 (se=76) more for those with insurance than for those in the control group. With rainfall data in the range of 6 to 9 hundred millimeters, this implies that the impact of insurance on harvest value goes from -$127 to $344 from the low end range of rainfall to the high end. The increase in responsiveness of output to rainfall in the capital grant is less precisely estimated ($125, se = 84), thus difficult to draw similar conclusions for the shift in riskiness for those in the capital group. The additive effect for both insurance and capital over the direct effects of each is also imprecisely estimated but oppositely signed, thus create an imprecisely estimated net null effect.

Columns 1 indicates that insured households invest more in total in their farms when rainfall is better (Column 2-6 indicate the breakdown, and we see more sensitivity of chemical use than others, which is intuitive as this is an input that can be more reactive over time to changes in weather conditions). The models of sections 2 and 5, in which *x* is determined before the realization of the state, therefore, miss an important dimension of agricultural activity in this region. As Fafchamps (1993) showed, agricultural production is a process that unfolds gradually as the seasonal weather realization is revealed. A fundamental characteristic of rainfall index insurance is that payouts are independent of farmer actions. This does not imply, however, that farmer actions in response to the realization of rainfall shocks are unaffected by insurance. These effects from the insurance only group are particularly strong for purchased inputs – chemicals and hired labor; the estimates are too noisy to see any effect on the amount of family labor. The capital only group does increase its investment in chemicals and family labor as rainfall increases (although as noted above, the aggregate measure is not significant statistically).[13]

Finally, Column 7 of Table 4 shows that insured farmers shifted the mix of their crops to highly-rainfall sensitive maize, the crop for which the insurance product was designed. Insured farmers increased the share of their land planted to maize by 9 percentage points (se=3, control group farmers planted maize on 31% of their cultivated acres). Capital grant recipients increased the share of their land planted with maize by 12 percentage points (se=3.4). Those who received both capital and insurance, however, did not shift more into maize production than those who received insurance alone (4 percentage points, se = 2.9).

Table 5 shows the heterogeneous effects of insurance and the capital grants across four key household characteristics. First we consider wealth. The interquartile range of wealth is approximately \$380. The effect of being insured on investment is approximately \$95 larger for a household at the 25th percentile of the wealth distribution than it is for a household at the 75th percentile. With decreasing absolute risk aversion, the introduction of insurance is associated with a larger increase in investment for households with a lower level of wealth. Similarly, we find that the impact of a capital grant is significantly less for a wealthier than for a less wealthy household, although this result is not statistically significant.

Three more interactions are explored in columns 2-4. For the quarter of households headed by someone who can read, insurance is associated with a much larger but also imprecisely estimated in investment than for the other three quarters of households in the sample (\$514, se = 251). Interpretation of this interaction is speculative, of course, but it may have something to do with the household's ability to understand the insurance product, or with the level of communication and trust established between the insurance sales agents and the household head. Farm investments by older household heads are also less responsive to insurance than those of younger heads (-\$12, se=6.6, per year); this also may reflect the trust established with the young sales agents or greater confidence in

[13] The differential sensitivity of input application to early season rainfall by insurance status raises interesting questions about dynamic production decisions over the farming season that are beyond the scope of the current paper, but that are accessible given the data we have collected.

financial innovations among younger household heads. There is no evidence of differential impacts of insurance according to the size of the household. In column 5, we simultaneously examine all four of these interactions. The wealth and age interactions with insurance both remain approximately as large and retain their statistical significance.

6.3 The Insurance Market, Heterogeneity, and Separation

In Table 6, we examine the effects of differential selection into the insured pool as the price changes as discussed in section 5.1, and also the separation implications of the availability of insurance, as derived in equation (18). Recall that for a given farmer, the treatment effect on investment of the availability of insurance is smaller when the insurance is sold at a higher price. However, at higher prices, more risk averse farmers differentially remain in the insured pool and the treatment effects on investment of insurance availability are larger for these farmers. We show in Table 6 that there is no strong evidence that one of these effects outweighs the other. To simplify the presentation, we consider a binary classification of prices into “low” (price less than or equal to GHC 4) and “high” (greater than GHC 4). With a strict threshold at 90%, only for family labor can we reject the null hypothesis that the impact of insurance is the same at high prices and at low prices (p=0.05; the $\chi^2(1)$ test statistic for the equality of the effect at low and high prices is reported for each investment in the final row of the table). However, two other results are close: land preparation costs (p-value of 0.104) and hired labor (p-value of 0.151), and ultimately harvest value (p-value 0.134).

In one of the years of our intervention, capital grants were randomly allocated to some households who also had access to (randomly priced) insurance. Where there is no basis risk, investment choices are independent of preferences and wealth. Conditional on the insurance price and the physical characteristics of the farm, investment should also be orthogonal to household wealth, household demographics, lagged shocks to profits, off-farm employment, or any other household characteristic. The concern is that such variables might be correlated with unobserved dimensions of land quality, which might affect the responsiveness of investment. The randomization of the capital grant ensures that in expectation there is no such correlation here.

We show in column 2 that conditional on purchasing insurance at a low price, receipt of a capital grant is associated with a large and statistically significant increase in expenditure on farm chemicals ($66, s.e.=16). There is no statistically significant effect of receipt of a capital grant at a low insurance price for any other input, nor for total farm investment (or output).

We showed in section 5 that if households have CARA preferences, investment will be invariant to the capital grant even if there is basis risk. However, for more general preferences we can expect investment to be increasing in the capital grant when the farmer has access to insurance but there is basis risk. For example, with CRRA preferences $\frac{u'(c)}{u'(c_H)}$ will decline with the receipt of a capital grant and thus investment will increase. However, this increase is observed only for chemical purchases.

6.4 Learning, Social Interactions and the Demand for Insurance

We are motivated to explore an alternative hypothesis associated with the trustworthiness of insurance by our observation (column 1 of Table 2, test at bottom of table, F-test 5.939, p-value =0.003) that insurance purchases at a given price are higher for those farmers who received a cash grant (but *not* higher for wealthier households (column 2)). This result is consistent with the hypothesis that farmers are not entirely confident that the promised insurance payouts will be made when trigger events occur (in the notation of 5.2, $\pi_N > 0$). If this concern is mitigated by the provision of the capital grant, then insurance demand and investment would respond as well.

There are alternative mechanisms that could increase the confidence of purchasers of insurance that π_N is small or zero. The two most obvious are one's own (good) experience with the insurance product, or one's friends and neighbor's experience with the product. Therefore, we estimate

(25)
$$\begin{aligned} I_{it} = {} & \gamma_{IP} I_{i.t-1} Pay_{i,t-1} + \gamma_{NP} I_{i,t-1}(1 - Pay_{i,t-1}) + \gamma_{SP} S(Pay)^{j}_{i,t-1} + \gamma_{SNP} S(NoPay)^{j}_{i,t-1} \\ & + \gamma_{SK} S(Capital)^{j}_{i,t-1} + \gamma_{Pay} Pay_{i,t-1} + \gamma_{SN} Num^{j}_{i,t-1} + \gamma_P P_{it} + X_{it}\gamma + \nu_{it} \end{aligned}$$

I_{it-1} is an indicator variable that farmer *i* had insurance in *t-1*. $Pay_{i,t-1}$ is an indicator variable that rainfall in the community of farmer *i* in *t-1* was such that there would have been an insurance payout in the community. $Num^{j}_{i,t-1}$ is the number of individuals in farmer *i*'s social network of type *j* in *t-1*. $S(Pay)^{j}_{i,t-1}$ is the fraction of members of that network who were insured and received a payout in *t-1*. $S(NoPay)^{j}_{i,t-1}$ is the fraction of members of that network who were insured and did not receive an insurance payout in *t-1*. $S(Capital)^{j}_{i,t-1}$ is the fraction of members of that network who received a capital grant in *t-1*. P_{it} is the price at which i is offered insurance. X_{it} is a vector which includes indicator variables for the second year, the sampling strata, and interactions of these.

The interactions of $I_{i,t-1}$ and $Pay_{i,t-1}$ are instrumented with interactions of the randomized prices at which *i* was offered insurance in period *t-1* and whether a payout trigger event occurred for *i*. $S(Pay)^{j}_{i,t-1}$ and $S(NoPay)^{j}_{i,t-1}$ depend on the insurance demands of individuals within *i*'s network; they are instrumented with the share of individuals within *i*'s network (of type *j*) who were offered insurance at each of the randomized prices, times the occurrence of a payout trigger event.

Estimates of (25) are presented Table 7. Each pair of columns represents estimates using a different definition of the social network: in the first, links are defined by pairs who have ever lent to or borrowed from each other; in the second links are based on family relationships; and in the third, links are based on sharing advice regarding farming. For each network type, results are presented using first the number of acres worth of insurance purchased and second using a binary indicator of insurance take up.

The first notable pattern is that current demand for insurance is strongly associated with an individual's lagged experience with payouts. A farmer who had insurance in the previous year and received a payout purchases 0.83 to 1.18 acres more insurance than a farmer who did not have insurance in the past year (the mean amount of insurance purchased, conditional on purchasing some insurance, is 5.5 acres, and 2.5 acres unconditionally). The result is similar for the binary outcome of take-up (Columns 2, 4 and 6; 8 to 11 percentage point increase in takeup over a mean take up rate of 43 percent among those offered insurance). Furthermore, and with important (and disturbing) implications for market development, a consistent and negative pattern is found for farmers who had insurance the prior year but did *not* receive a payout. These farmers purchased insurance for between 2.33 and 2.53 *fewer* acres than did farmers who did not have insurance in the previous year, and their take up of insurance was between 35 and 38 percentage points lower (all results significant with p-value < 0.01).

Our interpretation of this result is that farmers who receive a payout in *t-1* revise downward their estimate of π_N , the probability that a state will occur in which they should be paid but in which the insurer reneges, and that farmers who were insured but who do not receive a payout revise π_N upward.

The second notable pattern is that insurance demand is influenced by the payout experience of others within an individual's social network. For each of the three network definitions, an increase in the number of an individual's network members who had insurance and a payout last year is associated with an increase in the amount of insurance demanded, and an increase in the take up of insurance. These effects are statistically and substantively significant, but not as large as the effect from one's own experience. The number of acres purchased increases by 0.73 (se=0.23), 0.18 (se=0.06) and 0.15 (se=0.06) for each credit, familial relationship, and farming peer who receives a payout, respectively. Similar learning effects are found when examining the probability of buying any insurance (Column 2, 4 and 6). However, we observe no deleterious effects as we did for the direct effect of not receiving a payout: an increase in the number of peers who are insured and who do *not* receive a payout does not lower an individual's demand for insurance. It is possible that there is less discussion about the absence of payouts in these social networks than there is about the receipt of payouts.

There is also an increase in the demand for insurance associated with the share of one's family relationship and farming information networks that received a capital grant in the previous year. This finding is in accord with our earlier result (Table 2) that one's own receipt of a capital grant increases demand for insurance.

We interpret this pattern, as with that we find for one's own experience with the insurance, as providing evidence that there is not complete trust that payouts will be made, and that the extent of this mistrust is influenced by the experience a farmer and his social network have had with the product.

Two alternative interpretations exist: an income effect, and a behavioral recency bias. With incomplete insurance, farmers who received a payout last year could have a lower income than farmers who did not have insurance, and farmers who did not receive a payout could have a higher income than uninsured farmers. With increasing absolute risk aversion, that pattern could translate into changes in insurance demand with the signs we observe in Table 7. This logic carries over to realizations within social networks, provided that there is (unobserved to us) risk sharing within these networks.[14] The income effect interpretation, however, is not consistent with the finding that capital grants in one's social network increase insurance demand: if there are unobserved transfers this should be associated with a decline in insurance demand.

A second possible alternative interpretation of these results is behavioral. Rainfall patterns in the semi-arid tropics of West Africa exhibit no serial correlation (Nicholson 1993). However, our results so far are consistent with farmers who act otherwise. The results are consistent with "salience", or "recency bias", in which farmers who experienced a trigger event last year overestimate the probability of its reoccurrence this year and similarly farmers who did not experience a trigger event underestimate the probability of a payout this year. The effect of community level payout trigger events reported in Table 7 provides evidence that recency bias is indeed playing a role in insurance demand. This variable is an indicator equal to one if a rainfall event occurred last year that would have triggered an insurance payout to anyone with insurance in the respondent's community. We see that demand for insurance is significantly higher for individuals in communities that would have received a payout in the previous year. The available historical rainfall data for the region provide no support for the hypothesis that trigger events are serially correlated, so this appears to be an instance of recency bias. However, even conditional on trigger events occurring last year, both one's own actual experience with the insurance product, and the experience of members of one's social network remain important determinants of insurance demand. Thus both recency bias and the evolving degree of trust that payouts will be made when trigger events occur are important for the demand for index insurance.

7. Discussion

Several of these results resonate well with existing and ongoing research on agricultural risk markets and capital markets in other settings. Combining our results with lessons from complementary research provides us with some clear guidance on the mechanisms driving agricultural markets (and their failures). Such an understanding is helpful for companies, governments and other stakeholders who seek prescriptions for improved policies, and for researchers who seek a deeper and more robust understanding of capital and risk markets for agriculture in developing countries, including lessons on behavioral responses by farmers to policy changes from firms and government.

We start first by discussing the demand component of rainfall insurance. We then discuss the behavioral response to receiving insurance and capital on investment decisions by farmers. And last we discuss the implications here, as they relate to other literature, on the returns to capital for smallholder farmers.

[14] We have data on informal transfers, and there is no evidence of transfers associated with the realization of insurance payouts. However, it is possible that there are transfers that are not recorded in our data. There is qualitative evidence from focus group discussions and informal conversations with respondents of the importance of informal transfers: narratives on the intervention say that some farmers finance insurance with loans from informal networks.

The elephant in the room from prior studies is lack of demand for rainfall insurance, despite the evidence that risk impedes investment, and that investment likely has large marginal returns. In one of the first studies on demand for rainfall insurance, Giné and Yang (2009) shows that when rainfall insurance is bundled with credit (and priced at actuarially fair plus costs, hence likely market prices), demand for the credit actually falls. Their hypothesis was that the rainfall insurance should have made farmers *more* likely to be willing to take out the loan to invest in a new technology. To explain their finding, the authors conjecture that borrowers already had implicit insurance, in that they could default on their loan with bad rainfall shocks, thus the bundled insurance was actually overinsuring them, and thus likewise depressed demand for the credit.

From existing literature we are learning that many factors drive demand, such as trust (Cole et al, 2011), social networks (Cai, 2012), provision of financial literacy on insurance (Cai, 2012; Giné, Karlan and Ngatia, 2012), and also just simple framing and marketing of the insurance (Cole et al, 2011).

Price is a consistent driver, and not simply due to liquidity. The closest study to ours in terms of completeness of the range of prices tested is Mobarak and Rosenzweig (2012), and they find strikingly similar demand curves: 15% purchase rate at market prices (versus 11% in our study); about 22% purchase rate when priced at a 10% discount off of market price (no comparable price point in our study); about a 38% purchase rate when priced at a 50% discount off of market price, thus about actuarially fair (versus 42% in our study at actuarially fair prices); and about a 60% purchase rate when priced at a 75% discount off of market price (versus 67% in our study when priced at about a 75% discount). Our additional price points are consistent, almost linear extrapolations, from the above. We are aware of one other study which randomized the price of rainfall insurance, Cole et al (2011). Although Cole et al tested a smaller range of prices, they found similarly steep elasticities.

The observed elasticity suggests several areas for further research, and policy exploration. First, we need to examine whether liquidity could explain the steep demand curve. In our setup the cash drop (and its announcement) came *after* the insurance sales, hence this, combined with the fact that wealthier individuals do not exhibit flatter demand curves, and combined with the fact that individuals in the insurance only treatment group in the Grant Experiment managed to increase investment substantially, suggests liquidity is not the driving factor. The exogenous variation in the Cole et al (2011) study does find important evidence that liquidity matters (at least in combination with a mental accounting story in which transfers by an NGO "stick" to that context and such proceeds are more likely to be used when if the NGO then offers to sell an item). The survey-payment drives up the demand for the insurance: when cash paid for survey completion equals the premium price, the take-up rate increased by 40 percentage points, a 150% increase in likelihood of take-up.

Given the strong evidence that price matters and that experience and trust matter as well, there are some clear paths forward for policy and research. First, insurance products may consider payout schemes that include high-probability events, not just extreme outcomes, or even insurance products that effectively have a savings component to it so that individuals get what they perceive as a payout in almost all states of the world. Such approaches are not uncommon in developing countries either, for example with car insurance policies that reduce future premiums when no claims are made (this also is a likely mechanism of dealing with adverse selection, not merely trust).

Second, and this is partly a research methods question, but also has policy implications, we need to determine whether mental accounting is a key factor or not in the purchase of insurance. Further tests could help illuminate this, for example by separating the liquidity shock entirely both in name (i.e., have it come from a separate entity) and in timing. Third, if liquidity is the issue (despite the above points), financing schemes could increase demand at higher prices. One obvious idea is to link to harvest proceeds, however this may have issues regarding incentives to side-sell at harvest in order to avoid loan repayment (see Giné and Karlan, 2012). Thus contracting issues would need to be worked out with respect to avoiding moral hazard on the loan to finance the premiums. Furthermore, given the small size of the premiums, transaction costs on financing may prove costly. Further ideas could involve bundling the insurance premium with input costs, or selling through mobile operators in ways similar to existing sales of life insurance (Tigo, 2012).

Given typically low take-up rates of the rainfall insurance, the complementary literature is light on investment response (statistical power issues make it difficult to detect, particularly given the difficulty in measuring many farm inputs precisely). Two exceptions to our knowledge in the recent literature are able to focus on investment response, and both find similar results as we do, that risk-taking and investment increase even absent any capital infusion. Cole et al (2012) employ the same approach we do in the first year of our study, providing insurance at zero price. Thus, as long as individuals trust the insurance provider, and basis risk is not a major issue (two nontrivial conditions, see Mobarak and Rosenzweig (2012) for clear evidence that basis risk matters), such “insurance drops” provide an estimate of the impact on behavior from merely removing risk with respect to rainfall on a general population, not just those who understand and take-up at a positive price. Similar results from Cai et al (2010) find in China that insurance for sows leads to higher investment in sows for those who are willing to buy the insurance.

Although finding an investment response is important, we also lack clear evidence on the capital constraints being a key impediment to investment. Note that we are not able to use our experiment to precisely test returns to capital, since labor inputs shift along with the provided capital. In a similar experiment, de Mel et al (2008; 2009) provide cash grants to microentrepreneurs and find returns for men around 80% but near zero returns for women. In their setting they find little shift in labor inputs, thus conclude that their measure is a measure of the returns to capital. In our setting, we find significant shifts in labor, and have no instrument for labor apart from the provision of capital, thus we are not able to separately identify labor and capital. We also note that even if quantity of labor remained the same, the quality may shift. Measuring returns to capital is not easy with simply one instrument. Instead our capital drops should be thought of as testing how investment behavior changes when capital constraints are relaxed.

In the agriculture space, returns to capital no doubt are not homogeneous across farmers, and naturally effective policy on risk and capital markets must take into consideration not just the potential returns to farmers from relaxing capital or credit constraints, but also the heterogeneity in returns across farmers. Suri (2011) demonstrates this clearly: in Kenya, Suri finds that low adoption of hybrid maize is driven by heterogeneity in returns. Other research has sought as well to estimate returns to capital, but stated more conservatively has found considerable heterogeneity Further research to tackle the returns to capital question would be quite fruitful.

8. Conclusion

Risk matters. Of course, we are not the first to discuss this in theory, or to show evidence of this. This project advances our knowledge by its comprehensive approach to dealing with both capital constraints and risk constraints for smallholder farmers, and tying the lessons to a model to help understand more about the underlying market failures that wreak havoc with the ability and willingness of the poor to invest more in their farms and increase their expected farm profits.

This paper also has an important lesson for the microcredit community, both researchers and practitioners. Although microcredit has traditionally focused on entrepreneurs, any lending in rural areas undoubtedly targets, whether directly or indirectly, smallholder farmers. We learn here however that capital constraints alone are not the problem, that risk is a key hindrance to investment and thus improved income and growth. Microcredit networks and infrastructure could be used to build in better risk management tools. Although there has been some attempt at this, it has traditionally been life insurance, not rainfall or agricultural insurance of some sort. We do learn here that mitigating risk alone, without an infusion of capital, does lead to higher investment. Thus the lesson should not be to simply bundle rainfall insurance with loans (as we learn from Gine and Yang (2009), this depressed demand for the loans), but rather to use the delivery infrastructure, and perhaps the trust that microfinance institutions or banks may have in the community, in order to market and distribute rainfall insurance.

We (and others) focus on rainfall insurance because it does not have adverse selection and moral hazard issues that are potentially problematic for crop or pest insurance. Further research is needed to understand whether such problems are solvable. Forty years ago many conjectured that adverse selection and moral hazard made credit markets impossible to succeed for the poor, yet decades of innovation in microcredit has shown these to be mostly solvable problems. Similar innovation on business processes, monitoring systems, and delivery vehicles to reduce information asymmetries and transaction costs could generate dramatic welfare improvements for the poor.

Lastly, for rainfall or other index insurance, we note several key lessons and areas for further research. First of all, we consider basis risk a critical and practical issue, and research indicates is a genuine and economically important impediment (and farmers understand the risk, at least qualitatively Mobarak and Rosenzweig (2011)). Furthermore, trust is a key issue, and this can be tackled through product design (increasing states of the world with payouts), proper linkage with trusted institutions, as well as proper regulation. Ultimately we see large investment responses to relaxing both credit and capital constraints, thus we conjecture that the rewards are larger than obstacles from a societal perspective. To make that link complete, however, we also need further work on returns, to understand whether impact on farm profits are low due to measurement issues, heterogeneity, or suboptimal investment decisions.

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Figure 1: Effect of Insurance and Cash Grants on Total Investment

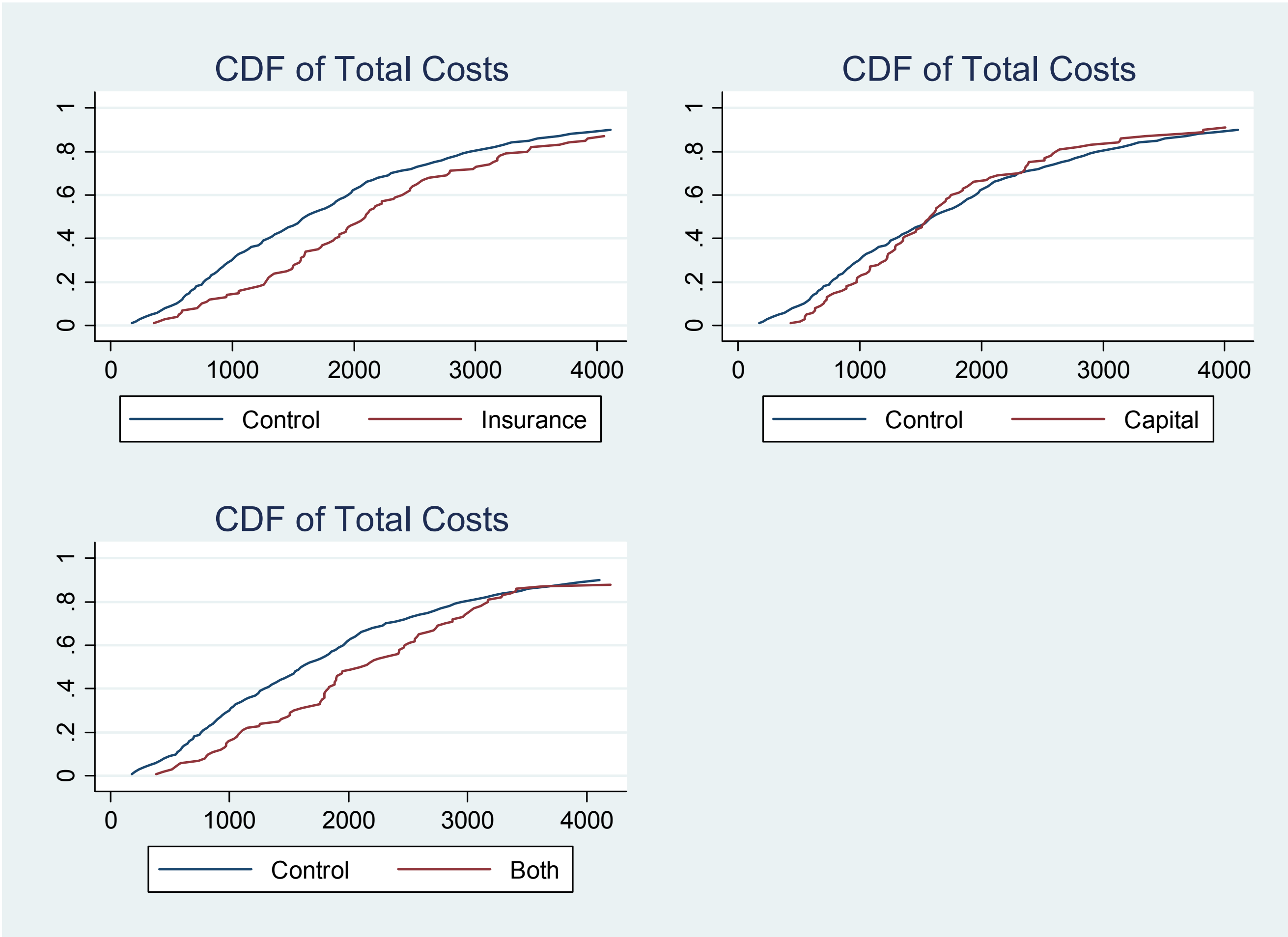

Figure 2: Effect of Insurance and Cash Grants on Chemical Expenditure

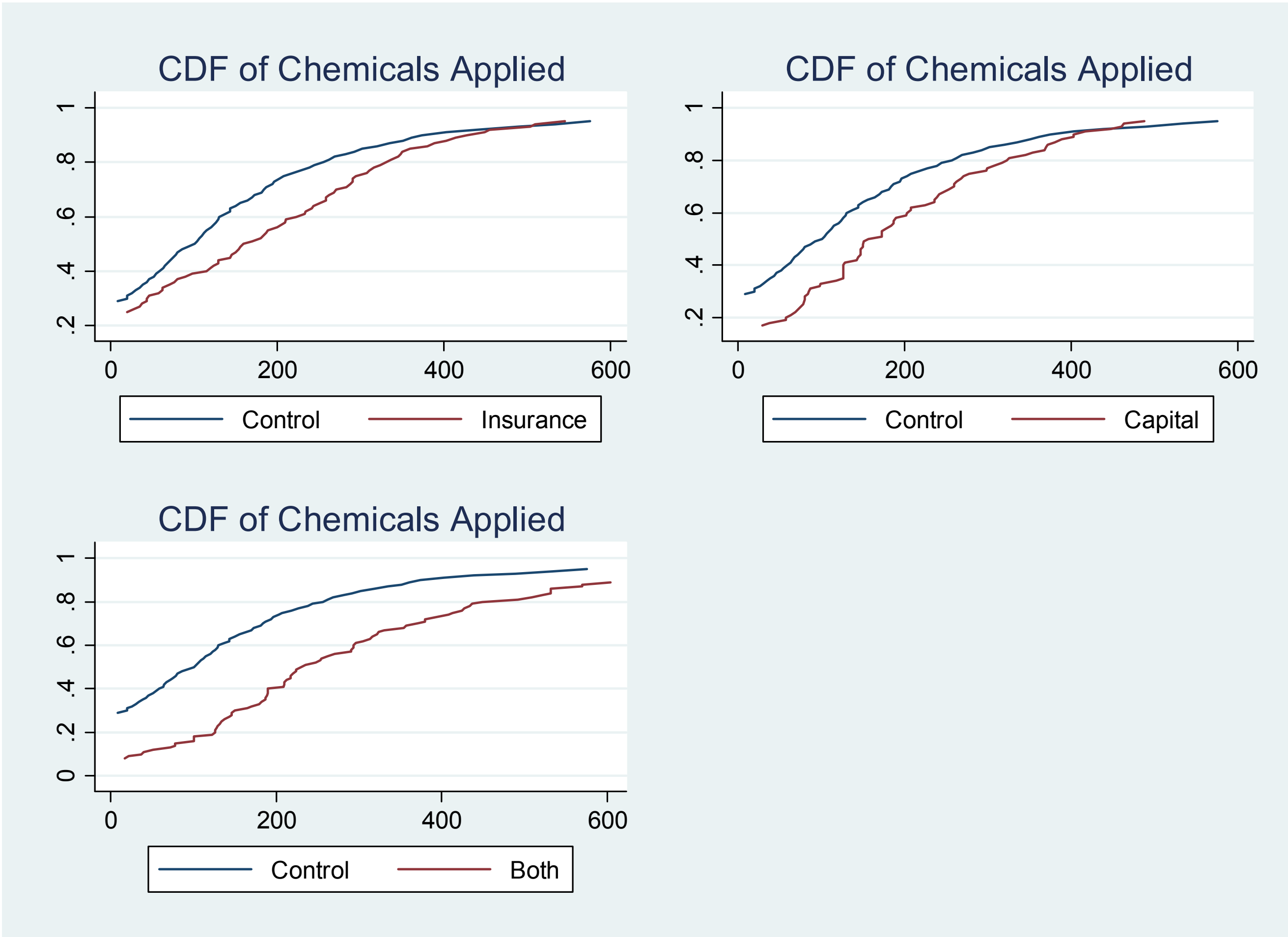

Figure 3: Effect of Insurance and Cash Grants on Area Cultivated

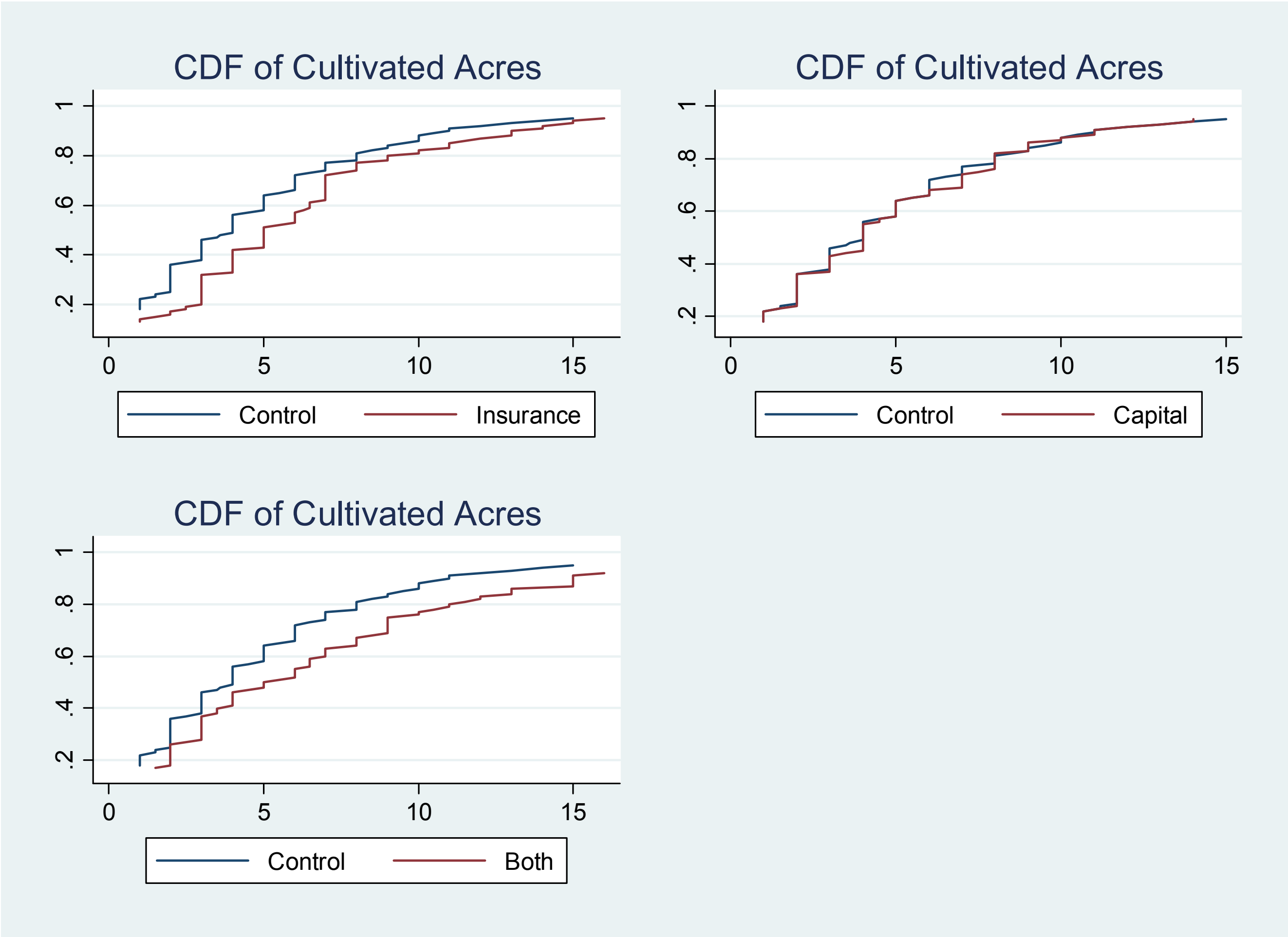

Figure 4: Effect of Insurance and Cash Grants on Value of Harvest

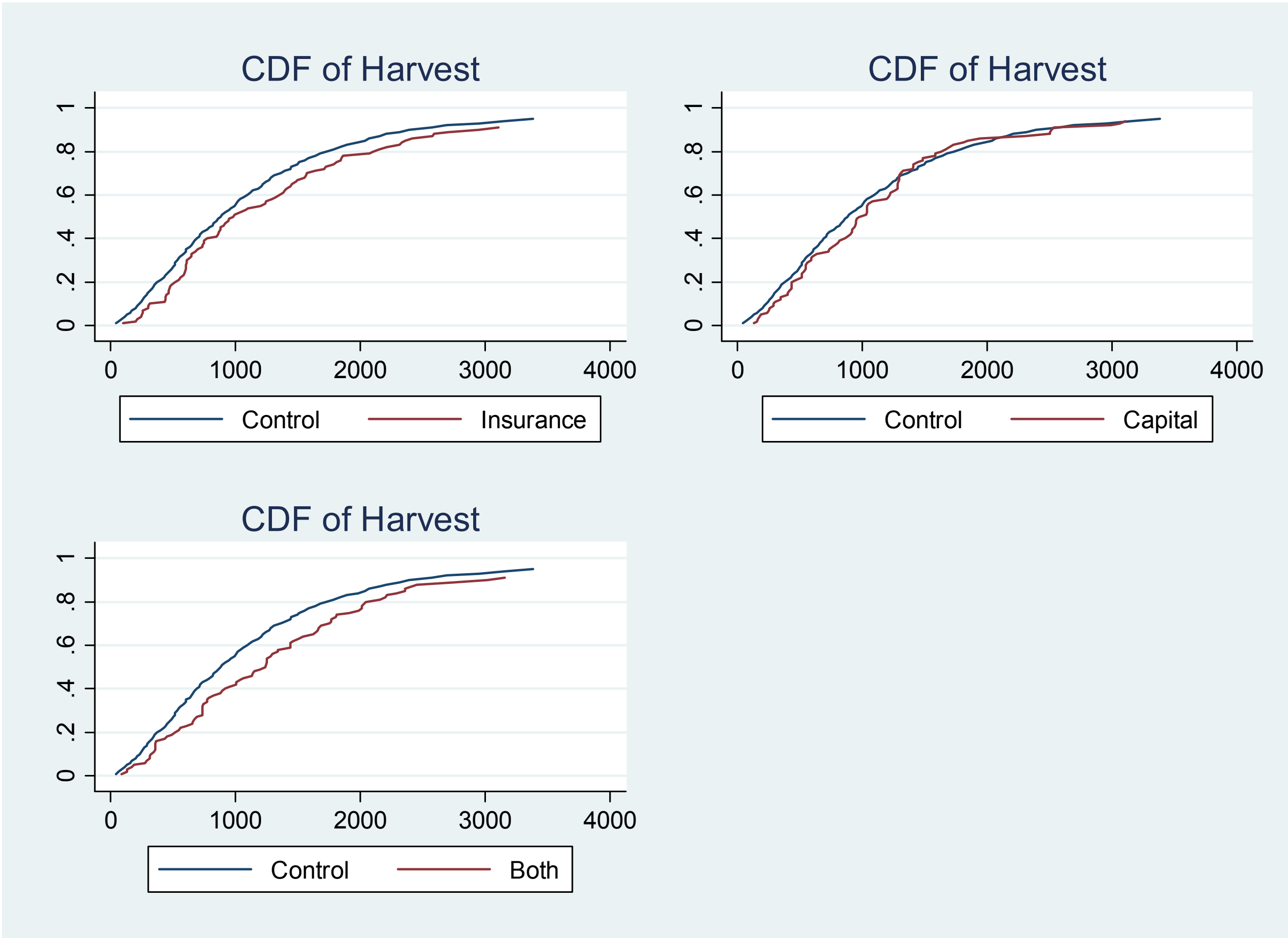

Figure 5: Insurance Takeup

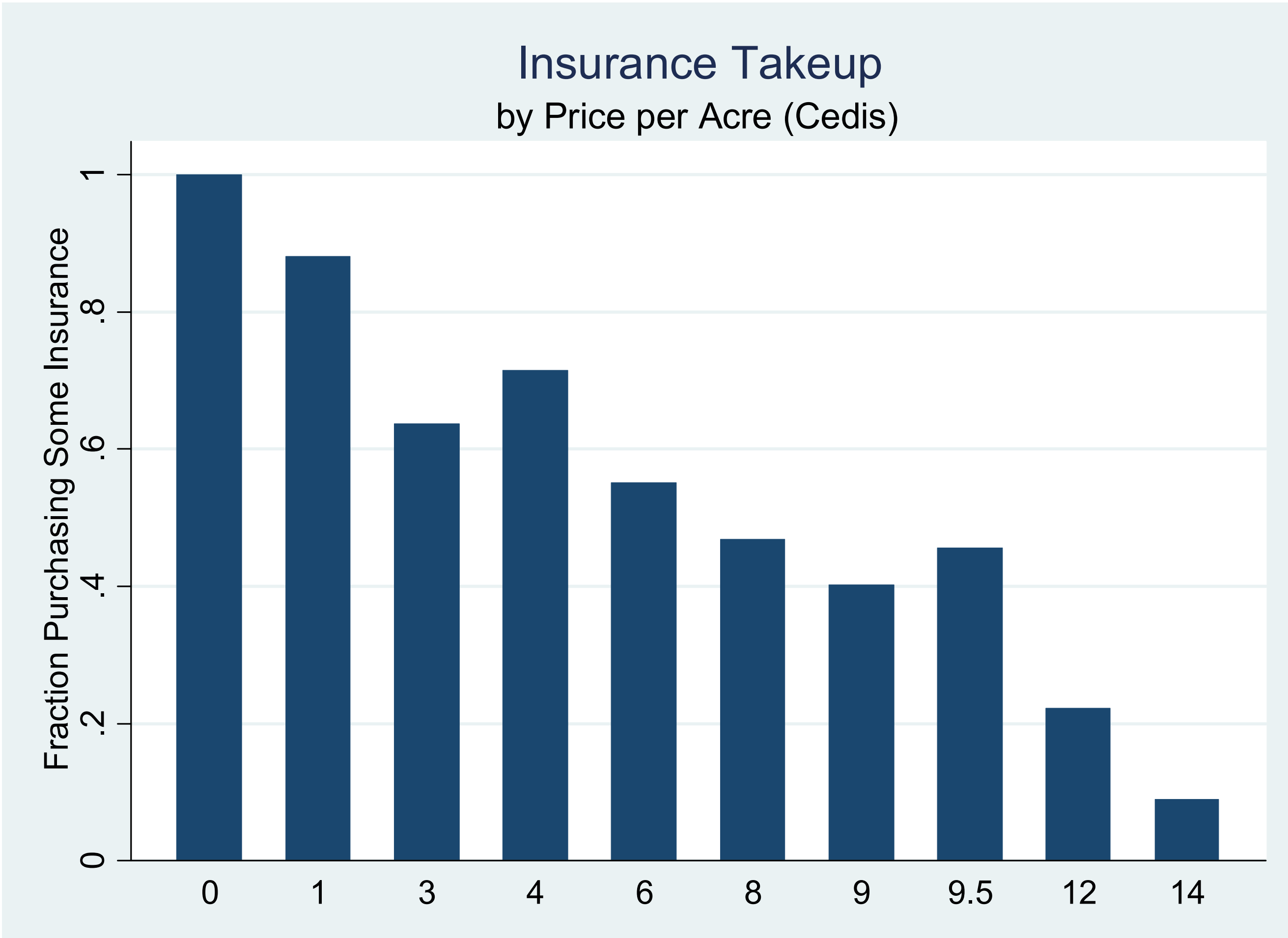

Figure 6: The Demand for Acres Insured

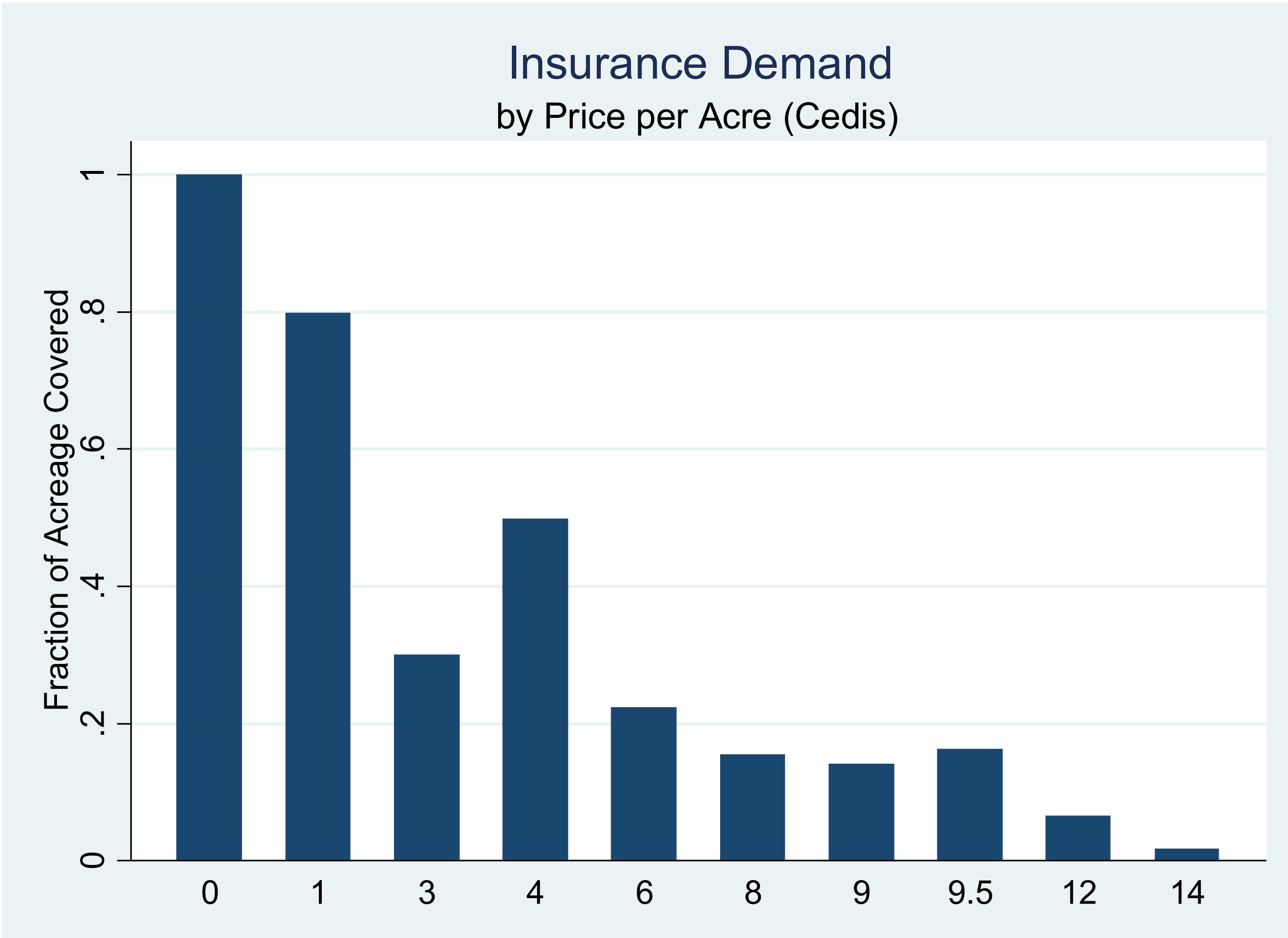

Figure 7: Northern Ghana Map with Rainfall Gauges and Farms in Study

Location of Communities and Rainfall Gauges in Northern Ghana

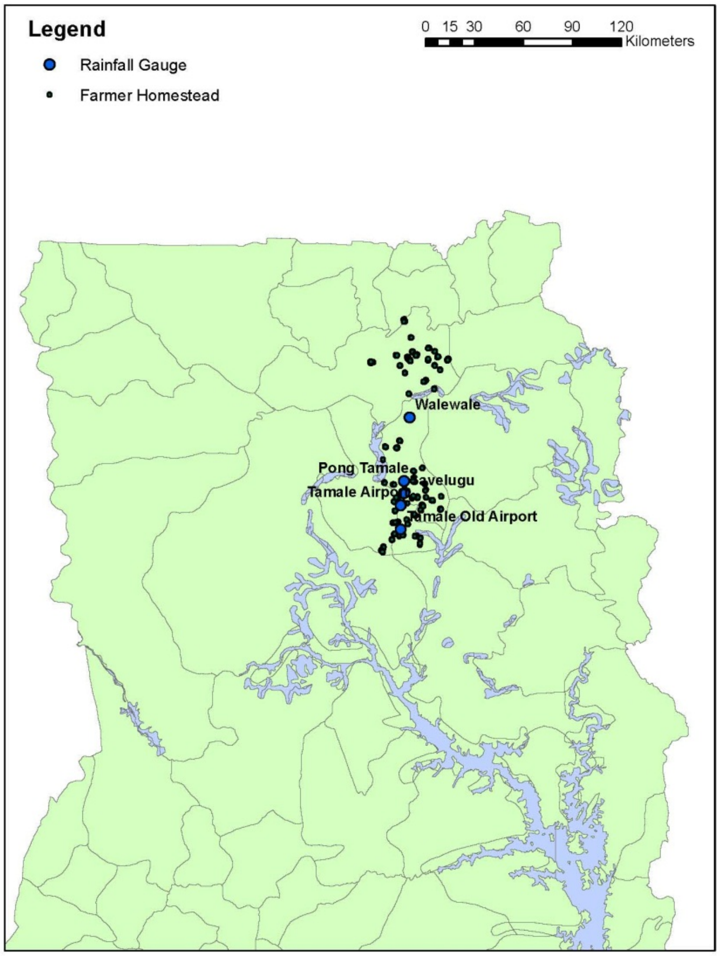

Table 1: Summary Statistics and Orthogonality
Mean (standard errors)

	(1)	(2)	(3)	(4)	(5)	(7)	(8)	(9)	(10)	(11)
Data Source:	GLSS5+						Year 1 Followup Survey			
	All	Both	Capital	Insurance	Control	F-test (p-value) from regression of var on both/capital/ insurance	Offered insurance @ 1 cedi	Offered insurance @ 4 cedis	Control	F-test (p-value) from regression of var on p=1/p=4
Household size	6.45	6.12	6.4	6.47	6.66	0.39	6.31	6.35	6.6	0.35
	(0.17)	(0.38)	(0.36)	(0.33)	(0.33)	(0.76)	(0.23)	(0.21)	(0.31)	(0.71)
Total acreage	7.8	8.44	7.33	8.17	7.43	1.49	6.26	5.03	6.29	2.78
	(0.21)	(0.67)	(0.37)	(0.39)	(0.35)	(0.22)	(0.44)	(0.37)	(0.57)	(0.06)
Cultivated acreage	7.02	7.31	6.75	7.17	6.91	0.40	4.59	4.17	5.00	1.00
	(0.19)	(0.53)	(0.36)	(0.32)	(0.33)	(0.75)	(0.36)	(0.36)	(0.43)	(0.37)
Total cost							1320	1118	1430	2.65
							(94.00)	(71.00)	(127.00)	(0.07)
Harvest value	233.67	300.66	181.86	226.36	238.07	1.97	794	647	764	2.07
	(15.96)	(54.70)	(22.02)	(21.86)	(29.91)	(0.12)	(62.00)	(44.00)	(62.00)	(0.13)
Chemical value	64.99	81.28	66.84	58.16	59.56	0.90	90	88	114	1.65
	(5.19)	(14.94)	(11.79)	(7.08)	(9.04)	(0.44)	(9.00)	(9.00)	(14.00)	(0.19)
Hired Labour							213	209	307	1.02
							(37.00)	(35.00)	(88.00)	(0.36)
Family Labour							901	720	883	2.24
							(77.00)	(52.00)	(76.00)	(0.11)
Head literate	0.15	0.15	0.15	0.13	0.18	0.58				
	(0.02)	(0.04)	(0.03)	(0.03)	(0.03)	(0.63)				
Head age	47.79	47.42	48.68	47.93	47.21	0.23				
	(0.68)	(1.55)	(1.45)	(1.31)	(1.22)	(0.88)				
F-test from regression of treatment assignment on all above covariates		1.49	0.71	0.46	1.03		1.59	1.48	0.70	
		0.17	0.66	0.86	0.41		0.12	0.16	0.69	
Observations		95	117	135	155		587	587	587	

Standard errors in parentheses. Total cost, hired labour and family labour data not available from GLSS5+ survey.

Table 2: Take-up of Insurance (First Stage)
OLS

	(1)	(2)	(3)	(4)
Dependent variable:	Insurance Takeup = 1	Insurance Takeup = 1	Insurance Takeup = 1	Insurance and Capital Takeup = 1
Insurance Price = 0	1.00***	1.00***	1.00***	
	(0.001)	(0.001)	(0.001)	
Insurance Price = 1	0.84***	0.89***	0.84***	
	(0.020)	(0.018)	(0.020)	
Insurance Price = 3	0.59***			
	(0.029)			
Insurance Price = 4	0.63***	0.70***	0.63***	
	(0.029)	(0.030)	(0.029)	
Insurance Price = 6	0.51***			
	(0.029)			
Insurance Price = 8	0.45***	0.47***	0.45***	
	(0.081)	(0.084)	(0.081)	
Insurance Price = 9	0.36***			
	(0.024)			
Insurance Price = 9.5	0.41***	0.42***	0.41***	
	(0.057)	(0.058)	(0.057)	
Insurance Price = 12	0.18***	0.17**	0.18***	
	(0.063)	(0.070)	(0.063)	
Insurance Price = 14	0.08**	0.09**	0.08**	
	(0.031)	(0.034)	(0.031)	
Insurance Price = 0 AND Capital Grant Treatment	1.00***	1.00***	1.00***	1.00
	(0.001)	(0.001)	(0.001)	(.)
Insurance Price = 1 AND Capital Grant Treatment	0.88***	0.89***	0.88***	0.87***
	(0.028)	(0.028)	(0.028)	(0.028)
Insurance Price = 4 AND Capital Grant Treatment	0.79***	0.78***	0.79***	0.78***
	(0.038)	(0.038)	(0.038)	(0.038)
Capital Grant Treatment	0.00	0.00	0.00	0.00
	(0.003)	(0.002)	(0.003)	(.)
Wealth at baseline		0.00		
		(0.001)		
Observations	3,314	1,801	1,908	1,908
R-squared	0.711	0.837	0.807	0.860
F-test: (p=1)=(p=1&CapitalGrant) & (p=4)=(p=4&CapitalGrant), i.e. whether demand differs at p = (1,4) for insurance with capital grant compared to demand at p = (1,4) without capital grant	5.939			
p-value	0.00266			

Robust standard errors in parentheses. Column 1 includes 3 years of demand data, Columns 2-4 include years 1 and 2 of demand data. Column 2 drops observations with missing wealth. All specifications include controls for full set of sample frame and year interactions (thus no constant). *** p<0.01, ** p<0.05, * p<0.1.

Table 3: Impact on Investment and Harvest
IV

Dependent variable:	(1) Total Costs	(2) Value of Chemicals Used	(3) Land Preparation Costs	(4) Wages Paid to Hired Labor	(5) Opportunity Cost of Family Labor	(6) # of Acres Cultivated	(7) Value of Harvest
Insured	266.15**	37.90**	25.53**	83.54	98.16	1.02**	104.27
	(134.229)	(14.854)	(12.064)	(59.623)	(84.349)	(0.420)	(81.198)
Insured * Capital Grant Treatment	72.14	66.44***	15.77	39.76	-52.65	0.26	129.24
	(138.640)	(15.674)	(13.040)	(65.040)	(86.100)	(0.445)	(81.389)
Capital Grant Treatment	2.44	55.63***	15.36	75.61	-130.56	0.09	64.82
	(148.553)	(17.274)	(13.361)	(68.914)	(92.217)	(0.480)	(89.764)
Constant	2,033.11***	171.70***	169.38***	201.88***	1,394.58***	8.12***	1,417.52***
	(124.294)	(13.804)	(10.603)	(45.383)	(84.786)	(0.399)	(90.635)
Observations	2,320	2,320	2,320	2,320	2,320	2,320	2,320
R-squared	0.009	0.041	0.017	0.005	0.006	0.143	0.012
Mean for Control	2058	158.3	189.1	327.9	1302	5.921	1177
Chi2 Test of Insured and Insured + Capital Grant Treatment	5.091	36.15	8.889	3.136	0.239	7.125	6.618
p value	0.024	0.000	0.003	0.077	0.625	0.008	0.010

Robust standard errors in parentheses. "Insured" instrumented by full set of prices (Table 2, Column 1 presents first stage regressions). Total Costs (Column 1) includes sum of chemicals, land preparatory costs (e.g., equipment rental, but not labor), hired labor, and family labor (valued at gender/community/year specific wages). Harvest value includes own-consumed production, valued at community-specific market value. All specifications include controls for full set of sample frame and year interactions. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Impact Heterogeneity with Respect to Rainfall

IV

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable:	Total Costs	Value of Chemicals Used	Land Preparation Costs	Wages Paid to Hired Labor	Opportunity Cost of Family Labor	# of Acres Cultivated	Proportion of Land Allocated to Maize	Value of Harvest
Insured	-1,444.90	-217.72**	32.76	-581.51	-535.56	1.25	0.09***	-1,069.13*
	(1,007.107)	(104.539)	(99.262)	(423.079)	(636.659)	(3.187)	(0.031)	(596.208)
Insured * Capital Grant Treatment	-1,418.68	116.49	248.21*	-92.00	-1,393.99*	1.69	0.04	1,324.48
	(1,221.387)	(154.222)	(147.360)	(554.052)	(789.219)	(4.616)	(0.029)	(821.152)
Insured * Total Rainfall	231.04*	33.44**	-0.17	89.99	86.55	-0.01		156.82**
	(128.855)	(13.358)	(12.502)	(55.632)	(79.978)	(0.401)		(76.291)
Insured * Capital Grant Treatment * Total Rainfall	190.56	-6.67	-30.10	15.60	172.79*	-0.19		-155.36
	(159.703)	(19.945)	(18.484)	(74.322)	(100.994)	(0.582)		(105.649)
Capital Grant Treatment	-1,419.02	-159.62	-12.84	363.82	-1,669.48**	-6.96*	0.12***	-879.77
	(1,042.954)	(121.387)	(108.595)	(444.460)	(670.159)	(3.737)	(0.034)	(642.233)
Capital Grant Treatment * Total Rainfall	189.60	28.03*	4.04	-35.30	202.11**	0.93*		124.95
	(133.680)	(15.650)	(13.695)	(57.148)	(85.670)	(0.475)		(83.589)
Total Rainfall (hundreds of millimeters)	5,156.68***	530.55***	233.91**	1,215.18**	3,306.62***	6.80**		2,247.39***
	(1,030.090)	(120.908)	(92.259)	(488.764)	(656.070)	(3.108)		(624.545)
Total Rainfall Squared	-342.29***	-34.50***	-15.79***	-74.82**	-225.95***	-0.49**		-146.65***
	(67.638)	(7.937)	(6.011)	(32.232)	(42.883)	(0.203)		(40.970)
Constant	-17,301.26***	-1,857.18***	-693.30**	-4,695.18**	-10,627.70***	-15.00	0.23***	-7,154.76***
	(3,912.114)	(458.888)	(353.617)	(1,846.393)	(2,505.944)	(11.893)	(0.016)	(2,375.086)
Observations	2,320	2,320	2,320	2,320	2,320	2,320	2,782	2,320
R-squared	0.024	0.057	0.022	0.021	0.023	0.154	0.090	0.021
Mean in Control	2058	158.3	189.1	327.9	1302	5.921	0.309	1177

Robust standard errors in parentheses. Columns 1-6 & 8: 2 years of agronomic data with nonmissing input data. Column 7 includes more observations because observations with missing input data are not dropped. "Insured" instrumented by full set of prices (Table 2, Column 1 presents first stage regressions). Total Costs (Column 1) includes sum of chemicals, land preparatory costs (e.g., equipment rental, but not labor), hired labor, and family labor (valued at gender/community/year specific wages). Harvest value includes own-consumed production, valued at community-specific market value. All specifications include controls for full set of sample frame and year interactions. Rainfall ranges from 6 to 9 hundred millimeters. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Investment Response, Heterogeneity with respect to Socioeconomic Covariates
IV

	(1)	(2)	(3)	(4)	(5)
Dependent Variable:	Total Costs	Total Costs	Total Costs	Total Costs	Total Costs
Insured	403.45***	134.39	815.32***	274.53	583.28
	(144.513)	(144.590)	(312.240)	(259.810)	(366.383)
Insured * Capital Grant Treatment	-26.05	105.20	-293.93	150.82	-208.20
	(159.086)	(156.459)	(404.963)	(317.762)	(495.209)
Insured * Wealth	-0.25*				-0.22*
	(0.143)				(0.117)
Insured * Capital Grant Treatment * Wealth	0.15				0.17
	(0.171)				(0.141)
Capital Grant Treatment	81.60	-92.89	670.04	-104.99	253.16
	(160.577)	(168.094)	(439.846)	(335.402)	(525.588)
Capital Grant Treatment * Wealth	-0.17				-0.10
	(0.159)				(0.159)
Wealth	0.37***				0.27***
	(0.088)				(0.087)
Insured * Head of Household Can Read		513.73**			450.89*
		(250.582)			(247.289)
Insured * Capital Grant Treatment * Head of Household Can Read		-189.52			-142.59
		(322.897)			(325.800)
Capital Grant Treatment * Head of Household Can Read		303.82			224.09
		(277.620)			(264.053)
Head of Household Can Read		-76.70			0.02
		(119.606)			(117.837)
Insured * Head of Household Age			-12.00*		-11.90*
			(6.551)		(6.508)
Insured * Capital Grant Treatment * Head of Household Age			7.90		11.39
			(8.598)		(8.753)
Capital Grant Treatment * Head of Household Age			-14.98		-12.19
			(9.433)		(8.892)
Head of Household Age			10.72***		3.76
			(3.546)		(3.447)
Insured * Household Size				0.68	31.54
				(32.262)	(32.966)
Insured * Capital Grant Treatment * Household Size				-8.97	-42.12
				(43.019)	(43.713)
Capital Grant Treatment * Household Size				17.72	38.73
				(45.485)	(43.809)
Household Size				132.15***	115.83***
				(15.500)	(16.341)
Constant	2,002.98***	2,059.20***	1,637.39***	1,068.18***	990.09***
	(124.703)	(132.364)	(194.400)	(159.855)	(212.122)
Observations	2,318	2,320	2,289	2,289	2,288
R-squared	0.029	0.012	0.013	0.074	0.090
25th percentile of covariate	94.15	0	30	4	
Mean of covariate	458.0	0.283	43.34	6.846	
75th percentile of covariate	474.0	1	53	9	

Robust standard errors in parentheses. Sample varies with missing interaction variable. "Insured" instrumented by full set of prices (Table 2, Column 1 presents first stage regressions). Total Costs (Column 1) includes sum of chemicals, land preparatory costs (e.g., equipment rental, but not labor), hired labor, and family labor (valued at gender/community/year specific wages). Harvest value includes own-consumed production, valued at community-specific market value. All specifications include controls for full set of sample frame and year interactions.*** p<0.01, ** p<0.05, * p<0.1

Table 6: Heterogeneity with Respect to Price of Insurance

	IV						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable:	Total Costs	Value of Chemicals Used	Land Preparation Costs	Wages Paid to Hired Labor	Opportunity Cost of Family Labor	# of Acres Cultivated	Value of Harvest
Insured at Low Price	277.13**	37.79**	22.52*	70.81	131.47	1.02**	132.83
	(136.950)	(15.118)	(12.371)	(61.057)	(85.847)	(0.428)	(81.910)
Insured at High Price	-47.91	40.95	122.36**	447.09*	-856.22*	1.10	-714.07
	(662.127)	(78.139)	(60.157)	(254.552)	(491.599)	(2.151)	(559.616)
Insured at Low Price * Capital Grant Treatment	68.05	66.46***	16.97	44.46	-65.05	0.26	118.58
	(139.018)	(15.700)	(13.158)	(65.224)	(86.343)	(0.446)	(81.473)
Constant	2,121.88***	170.79***	142.05***	98.72	1,665.24***	8.10***	1,649.33***
	(204.233)	(24.592)	(17.897)	(64.550)	(166.538)	(0.693)	(191.932)
Observations	2,320	2,320	2,320	2,320	2,320	2,320	2,320
F-test Insured at Low price = Insured at high price	0.231	0.00158	2.643	2.066	3.917	0.00122	2.242
p-value	0.631	0.968	0.104	0.151	0.0478	0.972	0.134

Robust standard errors in parentheses. "Insured at Low/High" instrumented by full set of low (0, 1 or 4) or high (above 4) prices . Total Costs (Column 1) includes sum of chemicals, land preparatory costs (e.g., equipment rental, but not labor), hired labor, and family labor (valued at gender/community/year specific wages). Harvest value includes own-consumed production, valued at community-specific market value. Controls included for capital grant treatment group and full set of sample frame and year interactions. *** p<0.01, ** p<0.05, * p<0.1

Table 7: Dynamics Effects of Prior Year Experience and Social Networks

IV

	(1)	(2)	(3)	(4)	(5)	(6)
Social network definition:	Borrowed or Lent	Borrowed or Lent	Related	Related	Farming Advice Given or Received	Farming Advice Given or Received
Dependent variable:	# of Acres Insurance Purchased	Purchased Any Insurance	# of Acres Insurance Purchased	Purchased Any Insurance	# of Acres Insurance Purchased	Purchased Any Insurance
Insured * Received Payout in Prior Year	1.18***	0.11***	0.92***	0.08***	0.83***	0.08***
	(0.300)	(0.028)	(0.321)	(0.028)	(0.316)	(0.028)
Insured * Did Not Receive Payout in Prior Year	-2.33***	-0.35***	-2.53***	-0.38***	-2.41***	-0.36***
	(0.654)	(0.078)	(0.641)	(0.078)	(0.628)	(0.077)
# Insured in Social Network that Received Payout in Prior Year	0.73***	0.06***	0.18***	0.01*	0.15**	0.02***
	(0.228)	(0.018)	(0.064)	(0.006)	(0.064)	(0.006)
# Insured in Social Network that Did Not Receive Payout in Prior Year	-0.11	-0.01	0.01	-0.00	-0.04	0.00
	(0.120)	(0.016)	(0.038)	(0.005)	(0.037)	(0.004)
Eligible for Payout in Prior Year	1.56***	0.14***	1.48***	0.14***	1.37***	0.13***
	(0.163)	(0.021)	(0.161)	(0.021)	(0.162)	(0.021)
# in Social Network that Received a Capital Grant in Prior Year	0.25	0.05	0.32***	0.04***	0.14	0.04***
	(0.319)	(0.030)	(0.120)	(0.012)	(0.126)	(0.012)
Constant	3.56***	0.67***	3.70***	0.64***	3.77***	0.67***
	(0.331)	(0.037)	(0.351)	(0.041)	(0.343)	(0.040)
Observations	2,189	2,189	2,189	2,189	2,189	2,189
R-squared	0.366	0.282	0.366	0.292	0.367	0.291
Mean of Dependent Variable	2.467	0.444	2.467	0.444	2.467	0.444

Robust standard errors in parentheses. Includes demand data from years 2 and 3. "Insured" instrumented by full set of prices (Table 2, Column 1 presents first stage regressions). "# in Social Network Insured" instrumented by # of individuals in the network offered insurance at each price. All specifications Include control for current year price, current year price squared, capital grant treatment status, acreage owned by household, control group in prior year, household size reported in prior year, size of social network, and size of social network that received capital in the prior year. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 1: Sample Frame Summaries
Observation Counts

Panel A: Experimental Cells	Sample Frame 1	Sample Frame 2	Sample Frame 3	Total
		New households in same communities as		
Communities:	Original communities	SF1	New communities	
Year 1 Grant Experiment				
Capital grant	117	0	0	117
Insurance Grant	135	0	0	135
Capital + Insurance Grant	95	0	0	95
Control	155	0	0	155
Total	502	0	0	502
Year 2 Insurance Product Pricing Experiment				
p=1 (PPP $US 1.30)	207	268	0	475
p=4 (PPP $US 5.25)	134	258	0	392
p=8/9.5 (PPP $US 10.50/12.50)	0	0	114	114
p=12/14 (PPP $US 15.85/18.50)	0	0	114	114
Control	161	150	0	311
Total	502	676	228	1406
Year 2 Capital Grant Experiment				
Treatment	0	363	0	363
Control	0	313	0	313
Total	0	676	0	676
Year 3 Insurance Product Pricing Experiment				
p=3 GHC (PPP $US 4.00)	105	168	57	330
p=6 GHC (PPP $US 7.90)	110	175	57	342
p=9 GHC (PPP $US 11.90)	126	183	114	423
Control	161	150	0	311
Total	502	676	228	1406
Panel B: Surveys				
Year 1 Followup/Year 2 Baseline				
Targeted	502	676	0	1178
Completed	481	587	0	1068
Year 2 Followup Survey				
Targeted	502	676	228	1406
Completed	465	579	208	1252
Panel C: Sample Size Explanations for Each Table				
Table 2: First Stage & Takeup				
Column 1: yr 1 and 2 and 3	1506	1352	456	3314
Column 2: yr 1 and 2, non-missing wealth	970	623	208	1801
Column 3: yr 1 and 2	1004	676	228	1908
Column 4: yr 1 and 2	1004	676	228	1908
Table 3: IV Agric Investment/outcomes				
All columns	946	1166	208	2320
Table 4: Rainfall				
Columns 1-6, 8	946	1166	208	2320
Column 7	988	1338	456	2782
Table 5: Interactions				
Column 1: wealth	946	1165	207	2318
Column 2: household head reads	946	1166	208	2320
Column 3: household head age	946	1155	188	2289
Column 4: household size	946	1155	188	2289
Column 5: joint	946	1154	188	2288
Table 6: Heterogeneity with respect to prices	946	1166	208	2320
Table 7: Dynamic Effects & Social Networks	682	1051	456	2189

Appendix Table 2: Homestead to Rainfall Gauge Distance Summary Statistics in 2009 & 2010

Gauge Location	(1) Mean Distance (km)	(2) Standard Deviation (km)	(3) Number of Farmers	(4) 2009 Mean Rainfall Amount (decimeters)	(5) 2010 Mean Rainfall Amount (decimeters)
Savelugu	8.36	7.15	264	6.74	-
Tamale Old Airport	6.69	3.56	171	7.02	-
Pong Tamale	11.98	6.42	392	6.12	6.05
Tamale Airport	13.37	7.64	469	7.44	5.97
Walewale	32.77	8.38	389	5.18	5.60

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