Do Index-Insured Loans Spur Technology Adoption?

Evidence from a Randomized Control Trial in Northern Ghana

Khushbu Mishra, Richard A. Gallenstein, Abdoul G. Sam, Mario J. Miranda,

Patricia Toledo, and Francis Mulangu[1]

Abstract

Adoption of advanced agricultural technologies in Sub-Saharan Africa remains disappointingly low, particularly among the millions of poor smallholders who account for most of the agricultural production. We conducted a two-treatment randomized control trial in northern Ghana to assess the impact of using drought-index insurance to insure the full repayable amount of agricultural production loans taken by smallholder farmers. In the micro-insurance treatment, any index insurance payouts go directly to farmers while in the meso-insurance treatment, payouts are directly sent to banks to be used to expunge farmer's debts. Overall, we find that bundling index insurance with loans spurs a significant increase in the adoption of some of improved production technologies considered in our study. In particular, micro-insurance of agricultural loans raises the use of compound fertilizer and selective herbicide by roughly 10 and 41 percent, respectively. Alternatively, we find no impacts of meso-insurance.

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[1] Mishra: Department of Economics, Stetson University; Gallenstein: Department of Economics, The Busch School of Business and Economics, The Catholic University of America (corresponding author, gallenstein@cua.edu); Sam and Miranda: Department of Agricultural, Environmental and Development Economics, The Ohio State University; Toledo: Department of Economics, Ohio University; Mulangu: Millennium Challenge Corporation. This research was funded by the U.S. Agency for International Development Feed the Future Innovation Lab for Assets and Market Access and supported in part by the Office of the Provost and Academic Affairs, Stetson University. We also thank our institutional partners in Ghana: the Ghana Agricultural Insurance Pool and the Association for Rural Banks.

1. Introduction

Smallholder adoption of advanced agricultural technologies, such as hybrid seeds and chemical fertilizer, remains disappointingly low in sub-Saharan Africa (SSA) despite the tremendous promise of these technologies to improve food security and rural incomes (Kassie et al., 2011; Mendola, 2007; Doss, 2006; Suri, 2011; AFSA, 2018). Among the factors that constrain technology adoption, production risks and poor credit access remain the most pervasive impediments. In fact, drought risk limits technology adoption both by discouraging costly investments that may be lost if crops fail and by limiting access to credit as banks are less likely to lend in risky environments (Boucher, Carter, & Guirkinger, 2008; Gebremariam & Tesfaye, 2018; Farrin & Miranda, 2015; Miranda & Gonzalez-Vega, 2011). We undertook a randomized control trial in Northern Ghana to investigate the impact of addressing both risk and credit constraints by bundling index insurance with agricultural credit for smallholder farmers. Our empirical results indicate that providing access to insured agricultural credit improves adoption of advanced production technologies.

In order to address the risk problems endemic to smallholder agricultural production in developing countries, researchers, practitioners, and policymakers have, over the past thirty years, taken a keen interest in the establishment of markets for agricultural index insurance (e.g., Barnett, Barrett, & Skees, 2008; Burke, de Janvry, & Quintero, 2010; Udry, 1990). Unlike conventional indemnity insurance, which indemnifies the policyholder based on his or her verifiable financial losses, index insurance provides payouts based on the observed value of a specified "index" that is highly correlated with financial losses, but cannot be influenced by the actions of the insured (Miranda, 1991). Given the widespread use of rain-fed agriculture, the indices most widely used in agricultural insurance contract designs in developing countries are rainfall indices. Index insurance, in principle, is free of the moral hazard and adverse selection problems that render conventional indemnity insurance prohibitively expensive in developing countries, and can be delivered at much lower administrative costs, making it more suitable for insuring smallholder production risk 4/4/2020 8:44:00 AM.

Numerous pilot programs and empirical field studies conducted throughout the developing world over the past thirty years have found that index insurance can have a positive impact on smallholder investment and advanced technology adoption decisions (Jensen & Barrett, 2017; Miranda & Farrin, 2012). For example, Karlan, Osei, Osei-Akoto, and Udry (2014) conduct a randomized control trial in Ghana offering farmers stand-alone index insurance policies and find that fertilizer use is significantly higher among farmers who obtained index insurance. Elabed and Carter (2015) report significant increases in investments in certified seeds by insured farmers in Mali. Several other studies such as Cai et al. (2015) also find positive effects of insurance on adoption of improved production technologies and higher returns on investment.

These benefits of stand-alone index insurance notwithstanding, recent theoretical research suggests that index insurance would be more effective at promoting smallholder adoption of advanced technologies if bundled with agricultural production loans (Carter et al., 2016; Farrin & Miranda, 2015; Miranda & Gonzalez-Vega, 2011). Bundling insurance and credit should reduce risk exposure for borrowers and protect lenders against widespread defaults in the event of a catastrophic drought. In fact, the reduction of systemic risk faced by lenders should result in increased supply of credit to finance agricultural investments (Giné & Yang, 2009; Marra et al., 2003; Mishra et al., 2019). Therefore, insured loans stand to simultaneously address the two leading constraints on technology adoption, production risk, and poor credit access.

The theoretical literature further suggests that the beneficiary of the index insurance payout and restrictions on its use can have important implications for the impact of index insurance on smallholder credit supply (Miranda & Gonzalez-Vega, 2011). Two approaches to bundling index insurance with smallholder loans have received attention among researchers and policymakers. For "micro-insured" loans, the borrower is the policy holder and beneficiary of the insurance product. Alternatively, for "meso-insured" loans, the bank is the policy holder and primary beneficiary on condition that insurance payouts are used to retire the borrower's debt obligation. Intuitively, micro-insured loans are more attractive to the smallholder since, in the event of a drought, the smallholder has the option to use the payout to finance household consumption rather than to repay their loan. In contrast, meso-insured loans are more attractive to lenders because they are the direct recipients of index insurance payouts which are then used to repay (fully or partially) smallholder loans.

In this paper, we report findings of a randomized control trial conducted in northern Ghana designed to investigate the relative impacts of micro- and meso-insured production loans on smallholder adoption of advanced production technologies. Our analysis is based on a two-treatment randomized control trial conducted with 258 maize farmer groups. In one treatment, farmer groups were invited by lenders to apply for production loans bundled with an index insurance contract that, in the event of a drought, pays the farmers directly (micro-insurance). In the second treatment, farmer groups were invited to apply for production loans bundled with an index insurance contract that, in the event of a drought, pays the lender directly on the condition that the payout be used to retire the farmer's debt obligation (meso-insurance). We find empirical evidence that providing farmers with access to insured production loans spurs an increase in smallholder adoption of advanced production technologies. In particular, access to micro-insured loans increases the likelihood of using compound fertilizer and selective herbicide by roughly 10 and 41 percent, respectively. Access to meso-insured loans, however, have no statistical impact on any of the inputs (compound fertilizer, straight fertilizer, broad spectrum herbicide, selective herbicide, and hybrid seed).

The remainder of the article is structured as follows. Section 2 discusses the design of our randomized control trial. Section 3 discusses the empirical strategy used to analyze the data, including the hypotheses to be tested and the econometric models employed. Section 4 presents and discusses our empirical results. Section 5 discusses the limitations of our study and Section 6 summarizes our key findings and offers concluding comments.

2. Experimental Design

Our randomized control trial (RCT) treatments were carried out during the 2015 and 2016 major growing seasons in the three northern Ghana regions: Upper East, Upper West, and Northern.[2] In these regions, smallholder agriculture is the dominant source of employment and farmers rely heavily on rain-fed agricultural practices, with maize being the dominant crop. The area faces the greatest threat of drought and lowest total rainfall in Ghana, making it a suitable location to investigate the impact of index insurance on investment in advanced production technologies.

2.1. Institutional Partners

We worked with two institutional partners in Ghana to implement our RCT: The Association of Rural Banks (ARB) and the Ghana Agricultural Insurance Programme (GAIP).

[2] In 2019, the Ghanaian government split the Northern Region into three new regions: North East Region, Northern Region, and Savannah Region. Our work takes place in the Upper East, Upper West, Northern, and North East Regions according to the new regional boundaries.

ARB is an organization that represents and provides services to a network of rural and community banks (RCBs) across Ghana. The RCBs were formed in 1976 by the Ghanaian government to promote financial market access in rural areas. RCBs operate in specified geographic, cultural, and linguistic areas with the mission of providing financial services, including credit, to rural enterprises and farmers. RCBs are presently the largest providers of formal financial services in rural areas, and account for about half of the total banking outlets in Ghana (Nair & Fissha, 2010). We specifically worked with the ARB-Northern Ghana Chapter, which represents the 16 RCBs operating in the Northern, Upper East, and Upper West regions of Ghana. Fourteen of the sixteen RCB members of the ARB-Northern Ghana Chapter participated in our RCT: Bangmarigu, Bessfa, Bongo, Bonzali, Borimanga, Buco, East Mamprusi, Lawra, Naara, Nandom, Sissala, Sonzele, Tizaa, and Toende. The RCBs primarily provide loans to farmers in groups, i.e., farmer-based organizations (FBOs) which are organized by farmers with assistance of extension agents from the Ministry of Food and Agriculture (MOFA) or in collaboration with the government-sponsored Northern Rural Growth Programme (NRGP). The FBOs are comprised of farmers that are interested in borrowing credit from the RCBs and are led by a group secretary and a leader. The FBO holds regular meetings and each season they apply for agricultural credit as a group and the RCBs approve loan applications at the FBO level. FBO members are jointly liable for loan repayment and therefore this structure follows a typical joint liability group lending scheme.

The Ghana Agricultural Insurance Programme is a private insurance company founded in 2011 by the Ghanaian government, the German Society for International Cooperation (GIZ), and Ghanaian insurance companies to help farmers manage agricultural production risks and promote adaptation to climate change (Ghana Insurers Association, 2015). At the time our project was implemented, GAIP offered a variety of indemnity and weather-based index insurance policies for maize, soy, and other leading crops and was the exclusive provider of agricultural index insurance in the country.

2.2. Treatment Arms - Insured Loan Contracts

In collaboration with GAIP and the fourteen RCBs from northern Ghana, we designed insured loan products that would serve as the basis for our experimental analysis. These insured loans combined a conventional agricultural loan from an RCB and a rainfall-based index insurance contract from GAIP.

Loan contract provisions varied across banks, but followed each bank's established policies and procedures. Loans generally provided smallholder groups with capital to purchase agricultural inputs including plowing services, fertilizer, herbicides, and certified seeds. Some banks offered predominantly cash loans, while others provided vouchers that could be redeemed for inputs. More specifically, five RCBs offered primarily cash loans (accounting for 92 FBOs) and nine RCBs offered primarily in-kind loans (accounting for 166 FBOs). The loan contracts typically required borrowers to begin repaying at harvest with the full repayment due ten months after the issuance of the loan.

We used existing GAIP index insurance contracts, designed for the maize crop, to insure the agricultural loans. GAIP offers contracts based both on government meteorological station rainfall and estimates of rainfall computed using remote-sensing data from the U.S. National Oceanic and Atmospheric Administration. The insurance contract makes payouts using a three-trigger mechanism designed to closely match the rainfall input needs for maize over its three major agronomic phases (Stutley, 2010). The first payout, which occurs at the conclusion of the germination phase, is based on the total number of dry days (days with less than 2.5mm of rain) during the germination phase. The second payout occurs at the conclusion of the crop growth phase and is based on consecutive dry days during the period between germination and flowering. The third payout occurs at the end of the flowering phase and is based on total quantity of rain during the flowering period. The specific triggers and time periods vary by location due to variations in the start and end of the growing season.

The insured loans combine the insurance contract from GAIP and the loan contracts from the participating RCBs. Using access to insured loans as the interventions, we randomly assigned FBOs to one of the following control or treatment groups:

- Control (Uninsured loans): FBOs were invited to apply for conventional uninsured agricultural production loans.
- Treatment 1 (Micro-insured loans): FBOs were invited to apply for micro-insured loans.
- Treatment 2 (Meso-insured loans): FBOs were invited to apply for meso-insured loans.

Farmers in uninsured, micro-insured, or meso-insured loan assignments were offered the opportunity to apply for loans following established bank policies and procedures with no guarantee that their loans would be approved.[3] For FBOs that applied and were approved for insured loans, the research team purchased insurance contracts covering the value of the loan (principle plus interest) issued by the RCBs and provided them to farmer groups and banks at no cost to them; subsidizing the insurance premiums is in keeping with recent research (Karlan et al., 2011, 2014). For micro-insured loans, insurance payouts were assigned directly to the individual

[3] FBOs in treatment groups were only able to apply for the insured loan offered, they did not have the option to apply for uninsured loans.

borrower whereas for meso-insured loans, payouts were assigned directly to the bank, on condition that they use the payout to retire the borrower's debt obligation.

2.3. Implementation and Timeline

In November 2014, we obtained a list of 791 potential and current FBO clients of the fourteen participating RCBs. From these, we selected 258 FBOs that met all of the following four criteria: (i) the FBO is a current borrower, eligible FBO but not a current borrower, or a past applicant that was denied a loan for reasons other than default; (ii) the FBO's primary or secondary crop is maize; (iii) the FBO has between 7 and 15 members; and, (iv) the FBO takes out a loan not exceeding 10,000 Ghana Cedis (GH₵).[4,5]

We administered our baseline survey in February and March of 2015. We surveyed three randomly selected farmers from each FBO, resulting in a sample of 779 farmers.[6] Using the data collected during the baseline survey, we stratified our sample by region and borrower status in the year prior to the baseline. We stratified on region due to significant cultural and geographic differences among regions and on borrower status to account for differences among existing and new clients. After stratification, we randomly assigned FBOs to either the micro-insured, meso-

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[4] 1 GH₵ = 0.293 USD as of February 2015.

[5] RCBs had various requirements that determined if an FBO was eligible for credit however the RCBs typically required FBOs to have existed for some period of time and show evidence of regular meetings, and hold some saving in the RCB.

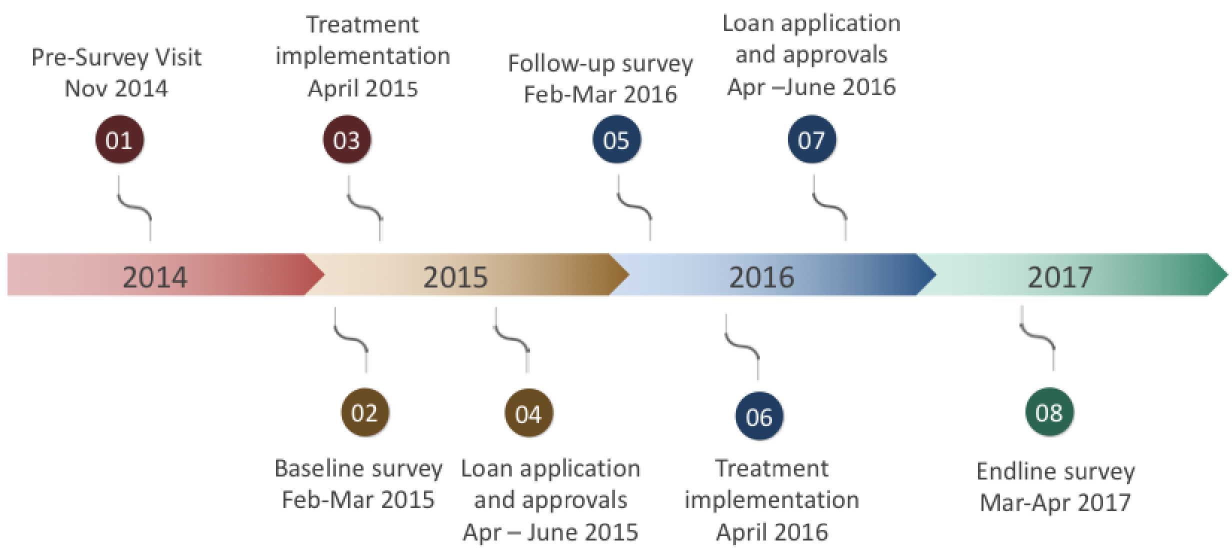
[6] Roughly three farmers per group with five additional surveys resulting from miscommunication in the field--on three occasions, enumerator teams accidentally collected more than three surveys from a farmer group.

insured, or uninsured categories. Using the baseline data, we conducted one-way analysis of variance to test whether there are any statistically significant differences between the means of the three categories and Kolmogorov-Smirnov test for equality in the distribution of continuous variables to ensure successful randomization (see Appendix, Tables A1 and A2).

The first treatment intervention was administered in the summer of 2015. GAIP aided us in training loan officers from each RCB on the design of the index insurance products and the specific insured loan contract structure. Subsequently, loan officers invited FBOs to apply for loans corresponding to their treatment assignments. After the invitations, FBOs followed their regular window of application and applied for loans in April to May 2015. Subsequently, in June 2015, the RCBs made loan approval decisions following their standard appraisal criteria and disbursed loans. Other than the risk protection afforded by the drought index insurance, no further benefit accrued to FBOs or RCBs with insured loans. The loan application and approval criteria, interest rates, payment schedules, and all other contract features for the insured loans were identical to those of conventional agricultural loans. One year after the baseline survey, we conducted a follow-up survey on 99% of the baseline sample from February to March 2016.[7] After the follow-up survey, we performed a second round of treatments identical to the previous year, following the same timeline and FBO categorizations as in the previous year. We then conducted a second follow-up survey from March to April 2017. See Figure 1 below for a complete map of the RCT process.

[7] A total of eight missing respondents were replaced by randomly selected farmers of the same gender from their respective FBOs.

Figure 1: Randomized Control Trial Process Map



Note: Figure 1 is borrowed with permission from [reference omitted during review for anonymity] because results stem from the same RCT.

2.4. Descriptive Statistics

Table 1 presents descriptive statistics of key variables across the three survey waves: baseline, follow-up 1, and follow-up 2. Panel B presents descriptive statistics for time-invariant variables.

Our five binary advanced production technology outcome variables are: use of compound inorganic fertilizer, straight inorganic fertilizer, broad spectrum herbicide, selective herbicide, and hybrid seed.[8] Compound fertilizer combines multiple nutrients; the dominant compound fertilizer is known as NPK, an acronym for nitrogen, phosphorous, and potassium. Compound fertilizer may be applied broadly across crops and is typically used once per growing season. In contrast, straight fertilizer contains just one of these nutrients; the dominant straight fertilizer in northern Ghana is

[8] We also collected data on insecticide use, but we found that no farmers in our sample used this input.

urea, which contains nitrogen. It is applied to specific crops at specific times during the growing season. Because it is a more precise and targeted intervention, straight fertilizer tends to require more technical knowledge to apply and is used less often. Likewise, broad spectrum herbicide is designed to target all categories of weeds and are often used as a substitute for manual weeding before sowing and plowing, whereas selective herbicides target a specific class of weeds, require more technical knowledge to apply, and are used as a substitute for manual weeding during the growing season (Africa Fertilizer, 2012; De Reflexion & Agricole, 2019; IFDC, 2012).

As seen in Table 1, the percentage of farmers in our sample who applied compound (straight) inorganic fertilizer varied between 86 and 90 percent (69 and 73 percent) across rounds. The use of broad spectrum (selective) herbicide ranged from 42 to 52 percent (19 to 26 percent) and the use of hybrid seed varied between 15 and 17 percent. Land planted to maize ranged between 2.6 to 2.9 acres while maize yields ranged between 326 to 362 kilograms per acre.

[Table 1]

We measured household wealth by collecting data on household asset ownership and remittance income. We found that households have on average four heads of cattle and roughly 100 GH₵ in remittance income in the baseline survey. We further collected data on perceived risk exposure and risk aversion. We measured the number of people the household may call upon for assistance in a time of drought (average of two at baseline), the farmer's recollection of the number of good farming seasons they experienced over the previous five years (2.36 at baseline), and measured risk aversion using a self-reported five-point Likert scale. Finally, we measured household characteristics such as age, education level, and household size.

We further conducted pair-wise mean t-tests to compare the treatment group uptake rates to the control group uptake rates for each outcome variable in each survey period and present these results in Table 2. We expect insignificant mean differences at baseline due to the randomization but significant mean differences in follow-up years due to treatment effects. We find no significant differences in means for most variables in most years. We do find a statistically significant reduction in uptake rates of broad-spectrum herbicides in follow-up 1. We also find a significantly lower level of uptake of selective herbicides for micro-insured loans at baseline, suggesting mild imbalance. This imbalance is not really concerning for our study since this would imply an downward bias in our estimates, if any. Furthermore, our balancing tests demonstrate generally strong balance in our sample. Lastly, we do not find significant differences between uninsured and meso-insured loans for any of the outcome variables. These unconditional mean difference results suggest very little impact of insured loans on technology adoption, and, in fact, some negative impacts on broad spectrum herbicide. However, these simple mean differences do not account for changes across time. Therefore, we move to our empirical analysis which will test for these impacts more rigorously.

Table 1: Descriptive Statistics of Key Variables per Survey Wave

Panel A: Samples means and standard deviations

Variables	Baseline Mean	Baseline Std. Dev.	Follow-up 1 Mean	Follow-up 1 Std. Dev.	Follow-up 2 Mean	Follow-up 2 Std. Dev.
Organic fertilizer	0.445	0.497	0.598	0.491	0.505	0.500
Inorganic fertilizer compound	0.862	0.345	0.901	0.299	0.894	0.307
Inorganic fertilizer straight	0.728	0.445	0.686	0.464	0.782	0.413
Herbicide broad spectrum	0.435	0.496	0.413	0.493	0.521	0.500
Herbicide selective	0.186	0.389	0.229	0.421	0.259	0.438
Hybrid seed	0.145	0.352	0.165	0.371	0.156	0.363
Acres planted to maize	2.90	3.59	2.66	2.78	2.62	3.17
Maize yield (kg/acre)	326	216	346	216	362	216
Saving (1=has savings)	0.68	0.47	0.79	0.41	0.71	0.46
Cattle	4.00	7.02	3.18	4.04	3.06	6.47
Remittances (GH₵)	100	204	124	223	97	193
Respondent age	45	13	46	13	47	13
Drought help	2.0	3.3	1.8	2.2	2.4	2.1
No. of good seasons, last 5 years	2.36	0.92	2.48	0.82	2.59	0.88
No. of household members	8.40	3.31	10.50	5.69	9.46	3.89

Panel B: Sample proportions of key variables

Gender (1= female)	0.47
Education	
Did not complete primary School	0.78
Completed primary school	0.05
Completed middle school	0.06
Completed secondary school	0.07
Completed university	0.04
Willingness to Take Risks	
Very willing to take risks	0.32
Willing to take risks	0.40
Indifferent	0.12
Not willing to take risks	0.15
Not at all willing to take risks	0.01

Note: Savings is with the bank; Drought help is the number of people the farmer can get help from in case of drought.

Table 2: Pairwise Mean Comparisons of Outcome Variables by Survey Wave

Outcome Variables	Uninsured loan	Micro-insured loan	Meso-insured loan
Input Types			
Compound fertilizer baseline	0.865	0.857	0.864
Compound fertilizer follow-up 1	0.903	0.897	0.903
Compound fertilizer follow-up 2	0.860	0.939	0.884
Straight fertilizer baseline	0.745	0.718	0.720
Straight fertilizer follow-up 1	0.674	0.693	0.690
Straight fertilizer follow-up 2	0.783	0.762	0.802
Herbicide Broad Spec baseline	0.456	0.412	0.437
Herbicide Broad Spec follow-up 1	0.457	0.360**	0.422
Herbicide Broad Spec follow-up 2	0.492	0.513	0.558
Herbicide Selective baseline	0.222	0.157*	0.177
Herbicide Selective follow-up 1	0.240	0.241	0.205
Herbicide Selective follow-up 2	0.260	0.273	0.244
Hybrid Seeds baseline	0.148	0.153	0.133
Hybrid Seeds follow-up 1	0.178	0.165	0.151
Hybrid Seeds follow-up 2	0.132	0.172	0.163
Land cultivated for maize (acres)			
Baseline	2.97	3.12	2.63
Follow-up 1	2.56	2.74	2.68
Follow-up 2	2.54	2.85	2.48
Maize Yields (kg/acre)			
Yields baseline	331	320	326
Yields follow-up 1	347	352	338
Yields follow-up 2	373	357	355

*** p<0.01, ** p<0.05, * p<0.1. Before finalizing our randomization, we conducted a balancing test on 25 variables from our baseline data set and found our samples balanced; this table is available in appendix table A1.

3. Empirical Strategy

3.1. Conceptual Framework and Hypotheses

Our empirical analysis is primarily devoted to testing whether access to index insured loans increases technology adoption, and if technology adoption further depends on whether the loan is micro-insured or meso-insured. As such, we propose to formally test the following two hypotheses:

Hypothesis 1: Access to insured loans increases the adoption of advanced production technologies.

Systemic production shocks (drought, flood, hail, wind, etc.) leave large portions of a bank's agricultural loan portfolio vulnerable to default, hindering the development of robust agricultural credit markets from the supply side (Farrin & Miranda, 2015). Similarly, farmers are more likely to choose low-risk investments such as well-understood and low-cost traditional production systems with limited use of technologies such as hybrid seeds or fertilizers in the presence of systemic risks (Banerjee & Duflo, 2007; Dercon, 2002). Therefore, by managing systemic default risk through bundling index insurance with agricultural loans, banks may be able to increase access to credit (Mishra et al., 2019; Carter et al., 2016) and spur agricultural technology adoption by relaxing farmers' capital constraints.[9] Moreover, index insurance should also increase advanced technology adoption by reducing the need for farmers to rely heavily on income smoothing to manage risk and therefore encourage riskier and high return investments such as fertilizer adoption (Ward et al., 2020). These theoretical and empirical studies suggest that insuring production risks and increased access to credit will incentivize greater technology adoption.

Hypothesis 2: Micro-insured loans have a greater effect on technology adoption than meso-insured loans.

Adoption of advanced production technologies imply financial and technological risks for smallholder farmers. The financial risk is due to farmers incurring large expenses that may be lost

[9] The impact of bundling index insurance with credit on credit market access is explored in detail elsewhere [citation excluded during review for anonymity]. Authors find evidence that bundling insurance contracts with credit increases the likelihood that smallholder farmers acquire loans.

if crops fail and the technological risk is due to adopting new technologies that may increase risk of agricultural production itself, especially when learning about proper use is required. These risks threaten household consumption which may be the greatest risk constraining adoption of these technologies.

Micro- and meso-insured loans have the potential to manage different risks and may result in different impacts on technology adoption. Meso-insured loans protect borrowers exclusively from default penalties including loss of collateral, which may be minimal due to limited liability (Giné & Yang, 2009), or loss of future loan access (Dougherty et al., 2020). Alternatively, micro-insured loans, by providing payouts directly to borrowers, may protect consumption directly. In fact, when collateral requirements are low (common in microfinance schemes (Flatnes & Carter, 2019; Morduch, 1999)), borrowers may use insurance payouts for consumption and default on their limited liability loans.[10,11] Therefore, micro-insured loans may more effectively crowd-in adoption of advanced production technologies by directly addressing the consumption risks that hinder technology adoption. In fact, Gallenstein et al. (2018) find a higher demand among smallholder farmers for micro-insured loans relative to meso-insured loans which reflects a preference to use insurance payouts for consumption rather than loan repayment.

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[10] With respect to consumption smoothing, there will be little difference between these insured loan products if credit contracts have high collateral requirements and no difference if the loan is fully collateralized. However, this is highly unlikely in rural microfinance.

[11] Our experiment takes place among banks that require 10 percent of loan principle as collateral and therefore our experiment is consistent with a low collateral environment in which meso-insured loans will provide little consumption smoothing.

Trust may also lead micro- and meso-insured loans to have differing impacts on technology adoption. If farmers have a low level of trust in either the insurance company or their bank, they may be concerned that insurance payouts under meso-insured loans will not be credited towards their outstanding debt, therefore they fear the meso-insurance will provide little protection even against default penalties. For new products such as index insurance, farmers may not trust the institutions fully and, therefore, even farmers that fear default penalties may respond more to micro-insured loans than meso-insured loans.

3.2. Empirical Model

Our empirical analysis involves two major steps. First, we gauge the empirical validity of our hypotheses by utilizing the following FBO fixed effects (FE) model:

$$Y_{igt} = \alpha + \boldsymbol{\beta}' \boldsymbol{T1_{gt}} + \boldsymbol{\theta}' \boldsymbol{T2_{gt}} + \boldsymbol{\gamma}' \boldsymbol{R_t} + RCB_{gt} + v_g + \varepsilon_{igt}. \quad (1)$$

Here, i, g, and t index individual, FBO, and survey wave, respectively. Y_{igt} is a binary variable indicating the use of each of the advanced agricultural inputs in our analysis. $\boldsymbol{T1_{gt}}$ and $\boldsymbol{T2_{gt}}$ are vectors of binary variables indicating FBOs that had access to micro-insured loans and meso-insured loans, respectively, over the two treatment rounds. $\boldsymbol{R}_t$ is a vector of dummy variables indicating follow-up 1 and follow-up 2 survey rounds. RCB_{gt} is a vector of RCB-year dummies that account for differences between banks and any changes in bank policies over the duration of the study. Given that RCBs operate in specific geographic and linguistic areas, these RCB-year controls also account for any location specific variation over time; this is important for our analysis as there were localized shocks during our intervention including some localized violence in the Upper East Region in 2015 and the ending of a Ghanaian government program for market access called the Northern Growth Programme (NRGP) that may have affected banks differently. v_g is the FBO fixed effect (i.e. the time invariant FBO specific component of the error term) and ε_{igt} is an error term.[12] The parameters of interest are $\boldsymbol{\beta}$ and $\boldsymbol{\theta}$, which measure the impacts of access to micro- and meso-insured loans on outcome variables, respectively, in each treatment year.[13] Based on our experimental design, we are identifying the average treatment effect on the treated (ATT) of access to insured loans, compared to access to uninsured loans, on technology adoption.

Second, we estimate the impact of insured loans on land cultivated for maize crop (in acres) and maize yields (in kilogram per acre). The importance of increased technology adoption lies in increasing agricultural production. Access to insured loans may increase agricultural production on both the extensive margin, as greater technology inputs and credit access may incentivize greater scale in production, and intensive margins, by improving crop yields through a combination of better soil nutrient content (fertilizer), reduced pest damage (pesticides), and use of higher yielding varieties (advanced seeds) (FAO, 2012; Hazarika & Awang, 2013; Duflo, Kremer, & Robinson, 2008). Therefore, we will assess the impact of insured loans on both land under

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[12] We also estimated an individual fixed effects model with clustered standard errors at the FBO level which produces qualitatively identical results; they are available upon request.

[13] We choose to disaggregate the impact of the treatments by intervention year, that is, the impact of micro- and meso-insured loans in 2015 and 2016 separately. We do this for two reasons: (1) in follow-up 2, we integrated the MOFA agents into our intervention which we believe improved the quality of our intervention by allowing MOFA agents to help farmers understand the implications of insurance and (2) a NRGP completed operations in 2016 and we believe that this may have affected credit access for our sample uniquely in the second year, i.e., follow-up 2.

cultivation to maize and maize yields using continuous land cultivated and yield variables as outcome variables in Equation (1).

4. Results and Discussion

Table 3 presents estimates from the FE model (Equation (1)) of the impacts of our insured loan products on advanced inputs: inorganic fertilizer, herbicides, and hybrid seed use. In each case, we first estimate the FE model without control variables (Model 1) and with bank-year dummies (Model 2) which control for RCB specific factors that vary across years.

For compound fertilizer, we find that access to micro-insured loans significantly increases the likelihood of its use by over 8 percentage points in the follow-up 2. This translates into a roughly 10 percent increase in compound fertilizer use relative to the baseline average of 86.5 percent among farmers in the uninsured loan (control) group (see Table 3). For selective herbicides, we find that access to micro-insured loans increase the likelihood of their use by over 8.1 percentage points in follow-up 1 and that the impact increases to 9.1 percentage points in follow-up 2, translating to an increase over the two rounds of 41 percent in the use of selective herbicide relative to the baseline average of 22.2 percent among farmers in the control group (see Table 3).[14] While we do not find similar positive impacts of micro-insured loans on straight

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[14] We acknowledge a statistical difference between the control group and treatment 1 group (at the 10% level) for selective herbicide at baseline. We do not believe that this challenges the balance for our sample as this is a difference significant at the 10% level while our sample balances across 20 variables in appendix Table A.1 and the 6 other outcome variables at baseline presented in Table 2. Moreover, this baseline difference is controlled for in our analysis with FBO fixed effects and more generally reinforces our results

fertilizer, broad spectrum herbicide, or hybrid seed adoption and no evidence that meso-insured loans increase adoption, the overall findings lend support to *Hypothesis 1* that access to insured loans have the potential to increase technology adoption.

The increased adoption of compound fertilizer and selective herbicides may be explained by their unique characteristics. Compound fertilizer requires less technical knowledge and may be the first type of fertilizer adopted by new adopters of fertilizer. Likewise, farmers adopting herbicides for the first time may first choose selective herbicides as a substitute for weeding as opposed to adopting broad spectrum herbicides; opting to rely exclusively on existing plowing practices to manage weeds prior to sowing.

We also find that micro-insured loans have a higher impact on the likelihood of technology adoption than meso-insured loans (as the latter do not have any significant impact on adoption for any of the survey waves). This finding lends support to *Hypothesis 2*. As we discussed earlier, micro-insured loans provide borrowers with the potential to smooth consumption whereas meso-insured loans offer borrowers only protection again default penalties. In low collateral environments, such that limited liability provides borrowers with implicit insurance, access to meso-insured loans may offer borrowers little additional protection against consumption risk relative to access to uninsured loans (Giné & Yang, 2009). Moreover, if farmers are not concerned with lost access to credit, which would be the case if credit constraints are not binding or if banks do not enforce dynamic incentives, meso-insured loans offer little risk management for borrowers relative to uninsured loans (Karlan et al., 2014). Alternatively, access to micro-insured loans offer borrowers some potential to smooth consumption in drought shock years which provides

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as the treatment group has significantly lower take-up at baseline than the control group.

borrowers with valuable risk management not available with uninsured loans. Therefore, smallholder farmers with access to micro-insured loans may be more willing to take the financial and technological risks associated with technology adoption. Trust may also play a role in borrowers' response to micro-insured loans relative to meso-insured loans. Our survey elicited farmers' level of trust in their bank and roughly 73% of the sample reported high or very high trust (on a 5-point Likert scale). Such high trust levels may indicate that lack of trust is not a significant driver of the divergence between micro- and meso-insurance in our results. However, given this RCT provided farmers with their first experience with meso-insurance, they may have had lower levels of trust regarding the bank's use of insurance payouts to repay outstanding debt obligations.

Table 4 presents the results from our FE model for the impact of access to insured loans on land used for maize cultivation and maize yields. Parallel to Table 4, we first estimate the FE model without control variables (Model 1) and then add bank-year dummies (Model 2). Contrary to our intuition, neither micro-insured loans nor meso-insured loans have any statistically significant impacts on land cultivated in any of the survey waves. Likewise, neither of these treatments have any statistically significant impact on maize yields for any of the survey waves. The lack of significant impacts on land under maize cultivation may be because farmers might be testing these new advanced technologies in their current farms first before expanding to new ones or may have a difficult time accessing additional farmland over short time horizons due to traditional land tenure systems in northern Ghana (Aryeetey & Udry, 2010; Goldstein & Udry, 2008). The lack of significant increases in yields is perplexing in light of recent literature demonstrating robust returns to such investments (Duflo, Kremer, & Robinson, 2008). The lack of results here may be due to farmers experimenting with these inputs on only a small part of their land and therefore we see an increase in adoption but there is too much noise to observe any

Table 3: Linear Probability Fixed Effects Model, Treatment Impacts on Technology Adoption

	Compound Fertilizer		Straight Fertilizer		Broad Spectrum Herbicide		Selective Herbicide		Hybrid Seeds	
VARIABLES	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Micro-insured*Follow-up1	0.004	-0.004	0.049	0.069	-0.057	-0.055	0.071	0.081*	-0.025	-0.024
	(0.036)	(0.035)	(0.061)	(0.050)	(0.058)	(0.052)	(0.046)	(0.043)	(0.040)	(0.038)
Micro-insured *Follow-up2	0.089**	0.083**	0.001	0.017	0.062	0.075	0.084*	0.091**	0.028	0.014
	(0.039)	(0.037)	(0.057)	(0.049)	(0.058)	(0.050)	(0.049)	(0.042)	(0.034)	(0.032)
Meso-insured *Follow-up1	0.000	0.003	0.040	-0.001	-0.013	0.009	0.013	0.001	-0.015	-0.032
	(0.038)	(0.038)	(0.065)	(0.052)	(0.060)	(0.053)	(0.048)	(0.045)	(0.039)	(0.038)
Meso-insured *Follow-up2	0.024	0.016	0.044	-0.004	0.088	0.082	0.033	0.022	0.041	0.038
	(0.039)	(0.039)	(0.058)	(0.048)	(0.060)	(0.055)	(0.050)	(0.043)	(0.037)	(0.035)
Follow-up 1	0.037	-0.008	-0.072	-0.088	0.002	0.21	0.016	0.33***	0.029	0.26
	(0.027)	(0.070)	(0.045)	(0.097)	(0.041)	(0.094)	(0.037)	(0.103)	(0.025)	(0.078)
Follow-up 2	-0.006	-0.025	0.036	0.211***	0.037	-0.036	0.035	-0.169***	-0.017	0.14
	(0.029)	(0.068)	(0.042)	(0.070)	(0.038)	(0.052)	(0.037)	(0.062)	(0.023)	(0.047)
Constant	0.862***	0.887***	0.728***	0.566***	0.434***	0.506***	0.185***	0.053	0.148***	-0.007***
	(0.009)	(0.066)	(0.015)	(0.059)	(0.014)	(0.043)	(0.011)	(0.052)	(0.009)	(0.043)
Bank-Year FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Observations	2,330	2,330	2,329	2,329	2,322	2,322	2,317	2,317	2,319	2,319
R-squared	0.001	0.031	0.012	0.120	0.015	0.072	0.010	0.60	0.002	0.033
Number of FBOs	258	258	258	258	258	258	258	258	258	258

*** p<0.1, ** p<0.05, *p<0.1. Robust standard errors reported in parentheses; Uninsured loan has been excluded from the dummy; a dummy variable is included for each bank-year as a bank-year fixed effect.

corresponding increase in yields. Alternatively, farmers may not be using optimal bundles of input packages and practices which may prevent any increase in average yields as evident in many other countries in SSA (Suri, 2011).

Table 4: Fixed Effects Model, Impact of Treatments on Maize Yields

	Land Cultivated (acres)		Maize yields (kg/acre)	
VARIABLES	Model 1	Model 2	Model 1	Model 2
Micro-insured*Follow-up1	0.070	0.35	17.139	12.675
	(0.36)	(0.214)	(24.60)	(23.537)
Micro-insured*Follow-up2	0.193	0.359	-4.394	-0.362
	(0.30)	(0.256)	(27.671)	(25.633)
Meso-insured*Follow-up1	0.470	0.498	-4.196	-3.171
	(0.30)	(0.303)	(23.809)	(24.102)
Meso-insured*Follow-up2	0.314	0.265	-12.267	-17.856
	(0.298)	(0.299)	(24.243)	(24.215)
Follow-up 1	-0.431***	0.335	14.398	-138.436***
	(0.162)	(0.428)	(15.502)	(49.026)
Follow-up 2	-0.443***	-0.346	42.9**	-47.425
	(0.180)	(0.422)	(19.051)	(49.026)
Constant	2.90***	2.77***	325.855***	417.224***
	(0.088)	(0.352)	(6.209)	(25.245)
Bank-Year FE	No	Yes	No	Yes
Observations	2,273	2,273	2,185	2,185
R-squared	0.004	0.126	0.007	0.035
Number of FBO	258	258	258	258

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors reported in parentheses; Uninsured loan has been excluded from the dummy; a dummy variable is included for each bank-year as a bank-year fixed effect; total acres planted includes three major crops in Follow-up 1 and two major crops in Follow-up 2; Primary crop yield includes maize plant primarily.

5. Limitations

Our study was conducted on a sample of farmers and FBOs that were existing or potential clients of rural banks. Therefore, our results are more relevant for populations of farmers with some experience with formal financial markets and especially with accessing credit. Our results may be less applicable to farmers with no past experience with the formal financial sector. In this regard, we expect the impact of insured loans to be higher than our estimates if insured credit is offered to a population without previous access to formal financial markets or advanced technologies. In our sample, farmers already had high uptake rates of many advanced technologies at baseline which limited the potential magnitude of the impacts, and our control group had access to uninsured loans. Combined together, these factors limit the potential impact of access to insured loans. In a population with lower baseline adoption rates and no previous access to credit, introduction of insured loans may yield substantially larger impacts by easing both financial and technology risks to a greater extent than is possible in our sample.

On the other hand, our experimental design includes features that may elevate the impact of insured loans in our case relative to a more generalized implementation of insured loans. First, the insurance premiums were fully subsidized in our experiment to improve uptake rates and ensure cooperation with rural bank partners (Karlan et al., 2011). If some or all of the insurance premium costs are passed onto borrowers, this may reduce credit uptake and potentially reduce the impact on technology adoption (Giné & Yang, 2009). Second, our sample included existing or potential clients of rural banks among whom there was a high level of trust in the banks and their loan officers. In a context in which insured loans are introduced among entirely new potential clients, lower trust levels may also reduce uptake of loans and/or insured loans in the short run. Moreover, in low trust environments, there be a greater divergence in the impact of micro- and meso-insured loans on individual farmer behavior.

There could be potential for spillover effects in our experiment. Roughly 41 percent of communities in our sample contain both treatment and control FBOs and therefore treatment farmers may have encouraged control farmers to adopt new inputs (Baerenklau, 2005; Besley &

Case, 1994; Conley & Udry, 2010; Foster & Rosenzweig, 1995; Mishra, Sam, Diiro, and Miranda, 2019). Moreover, if informal risk sharing networks span multiple FBOs within a community, the presence of an insured FBO within the community may lead uninsured farmers to also take on greater risks. In this manner, it is most likely that the spillover effect is positive leading us to underestimate the impact of access to insured loans on technology adoption and, therefore, potential spillovers do not threaten the integrity of our results.

6. Summary and Conclusions

Sub-Saharan Africa (SSA) may face a sixty percent increase in food demand over the next fifteen years (World Bank, 2016). This projection is especially concerning since this region has experienced decreasing agricultural outputs over the last decade (Suri, 2011). The low agricultural efficiency in the region is partly attributed to low adoption of modern agricultural technologies as a result of barriers such as systemic production risks which lead to a sub-optimal supply of loanable funds to the agricultural sector. We conducted an RCT in northern Ghana in which we investigated the impact of access to drought-index insured loans on technology adoption.

Using a fixed effects linear probability model, we find that access to micro-insured loans has a significant and positive impact on the adoption of inorganic compound fertilizer and selective herbicide. In particular, we find that access to micro-insured loans increases the likelihood of compound fertilizer and selective herbicide use by 10 and 41 percent, respectively, by the final year of intervention. These results are encouraging relative to other work that showed no improvement in technology adoption under insured loans (Giné & Yang, 2009; Karlan et al., 2011). We further expand the literature by evaluating the impact of insured loans by comparing micro- and meso-insurance. Contrary to micro-insured loans, we find no significant effects of access to meso-insured loans on technology adoption. The lack of a positive impact of meso-insurance could stem from two factors: (i) farmers' preference for the option of consumption smoothing afforded by micro-insured loans as funds are given directly to them in case of a payout trigger and (ii) a farmers' lack of trust that insurance payouts from meso-insurance will be used to forgive their loans when the payouts are given to the banks. Further work should be conducted to identify what conditions are necessary to elicit more robust technology investment responses from meso-insured loan clients. For example, meso-insured loans may require high levels of trust between farmers and the bank to be effective. Moreover, meso-insured loans may only be effective when default penalties are considerable and well enforced (Giné & Yang, 2009). Lastly, greater participation of various players in the value chain, such as input dealers, marketers, extension agents, and other aggregators, may be needed to generate higher return on credit-financed agricultural investments when farmers are insured.

We also evaluate the impact of insured loans on land cultivated and maize yields and fail to find evidence for a corresponding increase in either of these outcome variables. Given that the positive effects on technology adoption were more pronounced in the second year of the treatment, it is conceivable that farmers are experimenting with these inputs on existing farms (no extensification) and are in the process of learning how to apply optimal quantities or combination of these yield-enhancing inputs. In this sense, longer term studies could give us a better understanding of the impact of insured loans on technology adoption decisions and consequently yields as farmers may need time to respond to changes in their risk exposure. Furthermore, additional time may be necessary for farmers to adopt optimal input packages and practices to achieve increases in average yields.

References

Africa Fertilizer. (2012). *Training Manual on Fertilizer Statistics in Africa* [Technical Report]. International Fertilizer Development Center.

AFSA. (2018). *The Real Seeds Producers* (Technical Report). Alliance for Food Sovereignty in Africa. https://afsafrica.org/

Aryeetey, E. & Udry, C. (2010). Creating Property Rights: Land Banks in Ghana. *The American Economic Review*. 100(2): Papers and Proceedings of the One Hundred Twenty Second Annual Meeting of the American Economic Association (May 2010), pp. 130-134.

Baerenklau, K. A. (2005). Toward an Understanding of Technology Adoption: Risk, Learning, and Neighborhood Effects. *Land Economics*, *81*(1), 1–19. https://doi.org/10.3368/le.81.1.1

Banerjee, A. V., & Duflo, E. (2007). The Economic Lives of the Poor. *Journal of Economic Perspectives*, *21*(1), 141–168. https://doi.org/10.1257/jep.21.1.141

Barnett, B. J., Barrett, C. B., & Skees, J. R. (2008). Poverty traps and index-based risk transfer products. *World Development*, *36*(10), 1766–1785.

Besley, T., & Case, A. (1994). *Diffusion as a Learning Process: Evidence from HYV Cotton* (No. 174; Papers). Princeton, Woodrow Wilson School - Development Studies. https://ideas.repec.org/p/fth/priwds/174.html

Boucher, S. R., Carter, M. R., & Guirkinger, C. (2008). Risk Rationing and Wealth Effects in Credit Markets: Theory and Implications for Agricultural Development. *American Journal of Agricultural Economics*, *90*(2), 409–423. https://doi.org/10.1111/j.1467-8276.2007.01116.x

Burke, M., de Janvry, A., & Quintero, J. (2010). Providing Index–Based Agricultural Insurance to Smallholders: Recent Progress and Future Promise. *Documento de Trabajo. CEGA, University of California at Berkeley*.

Cai, H., Chen, Y., Fang, H., & Zhou, L. (2015). The effect of microinsurance on economic activities: Evidence from a randomized field experiment. *Review of Economics and Statistics*, *97*(2), 287–300.

Carter, M. R., Cheng, L., & Sarris, A. (2016). Where and how index insurance can boost the adoption of improved agricultural technologies. *Journal of Development Economics*, *118*, 59–71. https://doi.org/10.1016/j.jdeveco.2015.08.008

Conley, T. G., & Udry, C. R. (2010). Learning about a New Technology: Pineapple in Ghana. *American Economic Review*, *100*(1), 35–69. https://doi.org/10.1257/aer.100.1.35

De Reflexion, P., & Agricole, S. le C. (2019). ONZE FICHES DE CAPITALISATION D'EXPERIENCES DE CONSEIL AGRICOLE. *Inter-réseaux en France*.

Dercon, S. (2002). Income Risk, Coping Strategies, and Safety Nets. *The World Bank Research Observer*, *17*(2), 141–166. https://doi.org/10.1093/wbro/17.2.141

Doss, C. (2006). The Effects of Intrahousehold Property Ownership on Expenditure Patterns in Ghana. *Journal of African Economies*, *15*(1), 149–180. https://doi.org/10.1093/jae/eji025.

Dougherty, J., Gallenstein, R. A., & Mishra, K. (2020). *Impact of Index Insurance on Moral Hazard in the Agricultural Credit Market: Theory and Evidence from Ghana* [Working paper].

Duflo, E., Kremer, M., & Robinson, J. (2008). How High Are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya. *American Economic Review*, *98*(2), 482–488. https://doi.org/10.1257/aer.98.2.482

Elabed, G., & Carter, M. (2015). *Ex-ante Impacts of Agricultural Insurance: Evidence from*.

Farrin, K, & Miranda, M. J. (2015). A heterogeneous agent model of credit-linked index insurance and farm technology adoption. *Journal of Development Economics*, *116*(202), 199–211. https://doi.org/10.1016/j.jdeveco.2015.05.001

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change*, *33*(2), 255–298.

Flatnes, J. E., & Carter, M. R. (2019). A little skin in the game: Reducing moral hazard in joint liability lending through a mandatory collateral requirement. *Journal of Economic Behavior & Organization*, *164*, 199–214. https://doi.org/10.1016/j.jebo.2019.05.022

Foster, A. D., & Rosenzweig, M. R. (1995). Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture. *Journal of Political Economy*, *103*(6), 1176–1209.

Gallenstein, R. A., Mishra, K., Sam, A. G., & Miranda, M. J. (2018). Willingness to Pay for Insured Loans in Northern Ghana. *Journal of Agricultural Economics*, *0*(0). https://doi.org/10.1111/1477-9552.12317

Gebremariam, G., & Tesfaye, W. (2018). The heterogeneous effect of shocks on agricultural innovations adoption: Microeconometric evidence from rural Ethiopia. *Food Policy*, *74*, 154–161. https://doi.org/10.1016/j.foodpol.2017.12.010

Ghana Insurers Association. (2015). *Background and Development*. http://ghanainsurers.org.gh/?page_id=361

Giné, X., & Yang, D. (2009). Insurance, credit, and technology adoption: Field experimental evidencefrom Malawi. *Journal of Development Economics*, *89*(1), 1–11. https://doi.org/10.1016/j.jdeveco.2008.09.007

Goldstein, M. & Udry, C. (2008). The Profits of Power: Land Rights and Agricultural Investment in Ghana. *Journal of Political Economy*. 116(6): 981-1022.

Hazarika, G. & Alwang, J. (2003). Access to credit, plot size and cost inefficiency among smallholder tobacco cultivators in Malawi. *Agricultural Economics*. 29: 99-109.

IFDC. (2012). *Ghana Fertilizer Assessment*. International Fertilizer Development Center.

Jensen, N., & Barrett, C. (2017). Agricultural Index Insurance for Development. *Applied Economic Perspectives and Policy*, *39*(2), 199–219. https://doi.org/10.1093/aepp/ppw022

Karlan, D., Kutsoati, E., McMillan, M., & Udry, C. (2011). Crop Price Indemnified Loans for Farmers: A Pilot Experiment in Rural Ghana. *Journal of Risk and Insurance*, *78*(1), 37–55. https://doi.org/10.1111/j.1539-6975.2010.01406.x

Karlan, D., Osei, R., Osei-Akoto, I., & Udry, C. (2014). Agricultural Decisions after Relaxing Credit and Risk Constraints. *The Quarterly Journal of Economics*, *129*(2), 597–652. https://doi.org/10.1093/qje/qju002

Kassie, M., Shiferaw, B., & Muricho, G. (2011). Agricultural Technology, Crop Income, and Poverty Alleviation in Uganda. *World Development*, *39*(10), 1784–1795. https://doi.org/10.1016/j.worlddev.2011.04.023

Marra, M., Pannell, D. J., & Abadi Ghadim, A. (2003). The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: Where are we on the learning curve? *Agricultural Systems*, *75*(2–3), 215–234. https://doi.org/10.1016/S0308-521X(02)00066-5

Mendola, M. (2007). Agricultural technology adoption and poverty reduction: A propensity-score matching analysis for rural Bangladesh. *Food Policy*, *32*(3), 372–393.

Miranda, M. J. (1991). Area-Yield Crop Insurance Reconsidered. *American Journal of Agricultural Economics*, *73*(2), 233–242. https://doi.org/10.2307/1242708

Miranda, M. J., & Farrin, K. (2012). Index Insurance for Developing Countries. *Applied Economic Perspectives & Policy*, *34*(3), 391–427.

Miranda, M. J., & Gonzalez-Vega, C. (2011). Systemic Risk, Index Insurance, and Optimal Management of Agricultural Loan Portfolios in Developing Countries. *American Journal of Agricultural Economics*, *93*(2), 399–406. https://doi.org/10.1093/ajae/aaq109

Mishra, K., Gallenstein, R. A., Miranda, M. J., Sam, A. G., Toledo, P., & Mulangu, F. (2019). *Insured Loans and Credit Access: Evidence from a Randomized Field Experiment in Northern Ghana* [Working paper].

Morduch, J. (1999). Between the State and the Market: Can Informal Insurance Patch the Safety Net? *The World Bank Research Observer*, *14*(2), 187–207. https://doi.org/10.1093/wbro/14.2.187

Nair, Ajai and Azeb Fissha. (2010). "Rural Banking: The Case of Rural and Community Banks in Ghana." Discussion Paper 48, The World Bank, Agriculture and Rural Development Department, Washington, DC.

Stutley, C. J. (2010). *Government support to agricultural insurance: Challenges and options for developing countries*. World Bank.

Sunding, D., & Zilberman, D. (2001). *Chapter 4 The agricultural innovation process: Research and technology adoption in a changing agricultural sector* (B.-H. of A. Economics, Ed.; Vols. 1, Part A, pp. 207–261). Elsevier. http://www.sciencedirect.com/science/article/pii/S1574007201100071

Suri, T. (2011). Selection and Comparative Advantage in Technology Adoption. *Econometrica*, *79*(1), 159–209. https://doi.org/10.3982/ECTA7749

Tripp, R., & Rohrbach, D. (2001). Policies for African seed enterprise development. *Food Policy*, *26*(2), 147–161. https://doi.org/10.1016/S0306-9192(00)00042-7

Udry, C. (1990). Credit markets in Northern Nigeria: Credit as insurance in a rural economy. *The World Bank Economic Review*, *4*(3), 251–269.

Ward, P. S., Ortega, D. L., Spielman, D. J., Kumar, N., & Minocha, S. (2020). Demand for Complementary Financial and Technological Tools for Managing Drought Risk. *Economic Development and Cultural Change*, *68*(2), 607–653. https://doi.org/10.1086/700632

World Bank. (2016). *Operational Highlights*. http://www.worldbank.org/en/about/annual-report/overview

Appendix

Table A1. One-way Analysis of Variance (ANOVA) balancing test across baseline Control and Treatment Categories

Variables	Uninsured Loans	Micro-insured Loans	Meso-insured Loans	P-value
Maize quantity (KGs)	1,152	1,326	816	0.18
	(2,260)	(4,755)	(989)	
Fertilizer quantity (KGs)	520	372	332	0.53
	(2,865)	(1,534)	(1,182)	
Hybrid binary (1=use)	0.15	0.15	0.13	0.81
	(0.35)	(0.36)	(0.34)	
Number of loans taken	0.66	0.63	0.64	0.84
	(0.63)	(0.62)	(0.62)	
Default binary (1=defaulted)	0.16	0.15	0.17	0.84
	(0.37)	(0.36)	(0.38)	
Total income (GH₵)	2,269	2,210	2,141	0.62
	(1,592)	(1,441)	(1,434)	
Agricultural income (GH₵)	1,453	1,426	1,351	0.52
	(1,002)	(941)	(935)	
Time to input market (Minutes)	83	81	86	0.78
	(83)	(69)	(101)	
Aggregator binary (1=sell via aggregator)	0.36	0.40	0.36	0.59
	(0.48)	(0.49)	(0.48)	
Good season (1=2014 was good season)	0.40	0.42	0.40	0.91
	(0.49)	(0.49)	(0.49)	
Risk aversion (Likert Scale 1-5)	2.1	2.1	2.2	0.67
	(1.1)	(1.0)	(1.1)	
Maize planted land (Acres)	2.9	3.1	2.6	0.30
	(3.1)	(4.8)	(2.4)	
Price of maize (GH₵/ KG)	1.00	1.04	0.98	0.25
	(0.43)	(0.41)	(0.35)	
Remittance income (GH₵)	115	100	86	0.27
	(0.43)	(0.41)	(0.35)	
Proportion of plot planted with maize	0.42	0.42	0.45	0.33
	(0.22)	(0.24)	(0.40)	
Household size	8.6	8.4	8.2	0.33
	(3.2)	(3.3)	(3.4)	
Number of times households experienced these in the past 12 months				
Medical emergency	3.1	2.6	2.7	0.47
	(4.3)	(4.3)	(4.1)	
Borrowed cash/in-kind	0.57	0.62	0.52	0.55
	(0.99)	(1.00)	(0.99)	
Death in the family	0.44	0.43	0.45	0.95
	(0.85)	(0.77)	(0.86)	
Festivals	0.87	0.86	0.82	0.89
	(1.30)	(1.30)	(1.30)	
Crop loss	0.32	0.32	0.26	0.57
	(0.94)	(0.67)	(0.54)	

Notes: We present the means with standard deviations in parenthesis.

Table A2. Two-sample Kolmogorov-Smirnov test for equality in distribution of continuous variables

Variables	Uninsured & Micro-insured combined K-S	P-value	Uninsured & Meso-insured combined K-S	P-value
Maize quantity (KGs)	0.060	0.76	0.085	0.33
Fertilizer quantity (KGs)	0.034	1.00	0.090	0.25
Number of loans taken	0.020	1.00	0.015	1.00
Total income (GH₵)	0.051	0.88	0.062	0.69
Agricultural income (GH₵)	0.047	0.93	0.077	0.42
Time to input market (Minutes)	0.060	0.74	0.051	0.89
Risk aversion (Likert Scale 1-5)	0.072	0.53	0.050	0.91
Maize planted land (Acres)	0.040	0.99	0.108	0.11
Price of maize (GH₵/ KG)	0.059	0.78	0.059	0.79
Remittance income (GH₵)	0.052	0.87	0.058	0.78
Proportion of plot with maize	0.060	0.75	0.054	0.84
Household size	0.055	0.82	0.104	0.12
Number of times household experienced these in the past 12 months				
Medical emergency	0.080	0.38	0.052	0.87
Borrowed cash/in-kind	0.033	1.00	0.032	1.00
Death in the family	0.012	1.00	0.022	1.00
Festivals	0.053	0.85	0.058	0.78
Crop loss	0.0389	0.99	0.023	1.00