Seeds of Uncertainty: Information, subjective expectations, and technology adoption*

Emilia Tjernström and Jared Gars

University of Wisconsin, Madison

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Abstract

Poverty often goes hand in hand with a high degree of uncertainty about what the future holds, especially in rural areas of developing countries. Decision making under uncertainty at its core requires forming beliefs about the future, and acting upon those beliefs. Understanding how individuals form expectations, how they update them, and whether or not their actions are consistent with those beliefs is therefore crucially important to policy design in a range of domains such as agriculture, health, education, and many more. This paper uses a panel of Kenyan farmers, in which multiple moments of subjective beliefs distributions are elicited in each wave, to study how individuals update their beliefs in response to experimentally-varied information about a newly introduced technology. We document logical updating of farmers' belief distributions after being exposed to the treatment, as well as coherent associations between past experience with a related technology and first-period beliefs. We further explore the relationship between beliefs and uptake of the new technology, using a novel instrument for respondents' expectations. The instrumental variable regressions allow us to trace the effect of experimentally-varied information not only on beliefs, but all the way through to adoption behaviors. Our findings have implications for research on belief updating, technology adoption, and learning.

Keywords: Subjective expectations, Technology adoption, Belief updating

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1 Introduction

A key motivation for policy interventions that provide individuals with information is often that the potential beneficiaries are poorly informed. In developing-country settings, such interventions often take the form of information campaigns or learning subsidies designed to apprise poor populations of some new technology that they could benefit from adopting. The underlying assumption for why information or experimentation should affect technology adoption is that the population has prior beliefs about the returns to the new technology, but that these priors are centered around some mean that is lower than the true returns to the technology. Non-adoption could thus result if individuals maximize their subjective expected utility based on this flawed distribution of beliefs. Presenting individuals with information (as in Jensen, 2010), or with an opportunity to try a new technology (often through a learning subsidy as in Carter et al., 2014), is then thought to provide a signal that they can use to update their beliefs. Understanding how agents form expectations and the extent to which individuals update their beliefs according to the assumptions of standard economic models can both improve the design of similar information campaigns and contribute to our understanding of how individuals process information, with important implications for how we model and study learning.

As part of an emerging literature on subjective beliefs in developing countries (see Manski, 2004 for a survey of the literature in developed countries; Attanasio, 2009 and Delavande et al., 2011 survey the use of these methods in developing countries), we study the evolution of farmers' beliefs regarding a newly introduced hybrid maize variety in the context of a cluster-randomized information intervention in Kenya. To our knowledge, ours is the first paper to combine exogenous variation in information with panel data of multiple moments of subjective beliefs distributions. We use this data to test whether the sample farmers' belief updating aligns with the predictions of economic theory, to explore the relationship between beliefs and observed adoption behavior, and to examine the extent of treatment heterogeneity with respect to baseline characteristics.

We find evidence of logical belief updating, both based on own-experimentation and on the experiences of other farmers in the village: Being located in a treatment village, which entailed receiving information about, and samples of, a new hybrid seed, leads to higher mean expectations about hybrid seeds, an increased likelihood that farmers will prefer the new hybrids seeds to all other options, and an increased likelihood of adopting the new seeds.

We further explore the relationship between beliefs and actual adoption behavior. Since subjective expectations are likely endogenous in a regression examining adoption behavior, we instrument for expectations using an exogenous soil quality characteristic that is correlated with the returns to planting hybrid varieties. The instrumental variable regressions show evidence that farmers act according to their beliefs: those with higher expectations about hybrid seed returns are substantially more likely to adopt the new hybrids.

Our study improves on the literature connecting belief updating, learning and technology adoption in two key ways. First, our ability to trace the effect of experimentally-varied information on beliefs through to adoption behaviors has important implications for future studies of learning. Many empirical studies of information and technology adoption posit various learning models, but tend to use observed behavior to infer learning (see for example Conley and Udry, 2010 and BenYishay and Mobarak, 2014). This approach implicitly makes unverifiable assumptions about expectations and about how individuals process information. In light of the findings of much of the experimental literature on belief updating, the maintained assumption of Bayesian updating could be seen as worrisome.[1]

For example, the early psychology literature analyzing how subjects update simple probabilities found that individuals tend to rely on heuristics to process information, rather than on Bayes' rule (Tversky and Kahneman, 1974).[2] Several papers find that belief updating is asymmetric, with good news receiving higher weight than bad news (for example Coutts, 2016; and Mobius et al., 2011), but the results in Barron (2016) suggest that the asymmetry may be weaker in the domain of financial rewards. One reason for the discrepancy could be that financial rewards are a domain where participants have more experience, or that the setting feels more realistic than other lab implementations. However, asymmetric updating also appears to take place among college students updating their earnings expectations (Wiswall

[1]Much of the literature on belief updating has been carried out in the laboratory, largely because it is substantially easier to tightly control priors, innovations in agents' information sets, and information spillovers.

[2]Examples of such heuristics include the representativeness heuristic (relying too heavily on more recent, or more salient information) and the conservative heuristic (adjusting beliefs too little in response to new information).

and Zafar, 2014), a setting that can hardly be criticized for lack of realism. By documenting logical updating of beliefs among long-time farmers in a real-world setting, our results can help allay these concerns.

A second aspect that sets our paper apart from the small number of other studies that explore revisions to subjective expectations (Delavande, 2008 and Dillon, 2012) is that we have a credible instrument for respondents' expectations. There are many reasons to believe that individuals' expectations, as well as their propensity to update their beliefs, might be endogenous to their adoption of improved technologies. We employ as an instrument a soil quality characteristic that is uncorrelated with past farm management practices, but correlated with the returns to hybrid seeds and therefore with farmers subjective beliefs regarding hybrid yields.

Our data come from a three-wave panel survey of 1,800 households in rural Kenya, who participated in a randomized control trial (RCT) designed to evaluate the socio-economic impacts of a new hybrid maize seed. The seed is produced by a company called Western Seed Company (WSC), and were specifically developed for mid- to low-altitude farmers who had been under-served by the earlier hybrids released on the Kenyan market. Information about and samples of the company's high-yielding maize hybrids were rolled out in a cluster-randomized fashion to half of 107 villages.

Before the beginning of the study, the company had faced production capacity constraints and therefore had a limited geographic reach. The study villages were all located in the company's expansion areas; prior to the intervention most farmers in these areas had not had access to the seeds nor had they been exposed to information or marketing of the seeds. However, many of them will be familiar with some type of hybrid maize seeds – even though many may never have planted them. Farmers in treatment villages were invited to information sessions and were given a 250g sample pack of WSC hybrid seeds to plant on an experimental plot. This information intervention provides us with exogenous variation in the information available to farmers about the new hybrid variety.

We obtain the distributions of farmers' subjective beliefs over yields for two input combinations in each survey round: the respondent's current maize farming practices, and their stated preferred hybrid. We elicit subjective expectations using an interactive elicitation technique that is increasingly commonly used in developing countries (see e.g. Delavande et al., 2011): First, each participant defines the support of the yield distribution by answering questions about the best and worst possible yields that they could obtain on their field. Second, the interval between those two endpoints is divided into 5 bins. Third and finally, farmers allocate 20 beans, each representing a year out of the next 20, into the bins on the distribution. From this allocation, we fit a log-normal approximation for the responses and estimate the parameters of individual distributions using least squares, in particular the first and second moments of the distributions.

Section 2.2 describes the empirical setting, the sample households, and our methodology for constructing the moments of individuals' belief distributions. Section 3 discusses how the randomized information treatment affected farmers' beliefs, preferences, and behavior, and explores whether farmers update asymmetrically in response to good or bad news.

2 Data

This section describes our empirical setting and the construction of variables. First, we outline the study setting, the experimental design, and the timeline of the study. We then provide more details on the data collected and the sample households. Finally, we describe how the subjective expectations were elicited and how we obtain the moments of individuals' belief distributions.

2.1 Experimental design and sampling

This study takes place in the context of a larger randomized controlled trial (RCT), designed to evaluate the benefits of a new maize hybrid, produced by Kenya's Western Seed Company (WSC). While Kenya's domestic hybrid seed market has exhibited both greater variety and adoption than other countries in sub-Saharan Africa, the majority of seeds to date have been developed for the high-elevation zones of the Rift Valley; low- and mid-altitude zones have been relatively neglected. Following an infusion of impact investment capital, drawn in by the company's efforts to target niche markets with 'locally-focused seeds' tailored to the climatic and soil conditions of the mid-altitude regions, WSC was able to expand into new regions in Kenya. The RCT was designed to measure how access to WSC seeds impacted yields and incomes for households in the target zones, using a marketing strategy that provided farmers in treatment villages with information about the seeds, as well as sample seed packs for experimentation.

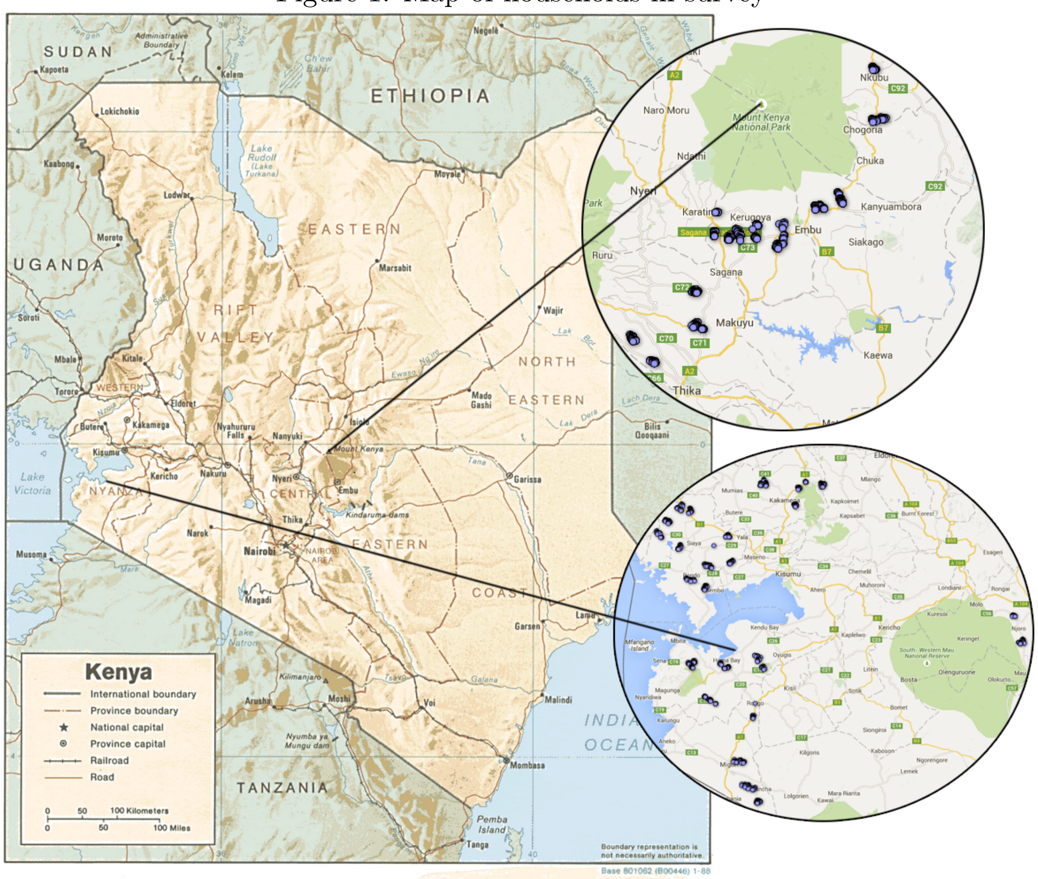
In a typical season, most seed companies in Kenya establish demonstration plots that showcase their products as part of their marketing strategy. Prior to the main season of 2013, WSC agreed to identify a surplus of demonstration plots in the study regions. Together with the company's marketing team, we created matched pairs from within the list of potential demonstration plots. One demonstration plot in each pair was then chosen at random for exclusion from the standard WSC marketing program. WSC agreed to engaging in other marketing activities in control villages during the period of the study, while operating as usual in the treatment areas.

Around the selected demonstration plots, the research team established "learning zones" by drawing a 5-km radius circle. Within these circles, villages were sampled by first showing local administrators maps of these circles to create a list of all the villages within a given circle. From these villages, three were selected at random for inclusion in the study.[3] Next, with the assistance of local chiefs and village elders, the team constructed a complete list of all the households in each of the selected villages. From these village lists, 50 households were selected from each learning zone for inclusion in the baseline study for a total of 1,800 sample households. Figure 1 shows the geographical distribution of households.

In treatment villages, households were invited to an hour-long information session about WSC and its hybrids prior to the main season of 2013. At the conclusion of the information session, participants received a 250-gram sample pack of the seeds. The 250-gram seed packs contained only enough seed for a small experimental plot and were not expected to affect yields during the 2013 season. The first wave of household surveys were administered 9 months later, after the main season harvest; households who planted the sample packs had therefore already harvested and observed the yields. Over 97 percent of treatment farmers reported experimenting with the seeds during the 2013 planting season.

[3]One circle only contained two villages, both of which were included in the sample. Most circles included substantially more than three villages.

Figure 1: Map of households in survey



The research team had also identified fertilizer use as a potential constraints to both adoption and impacts in part of the sample. Farmers in the western part of Kenya are substantially poorer and less productive than those in the central region, with around 2.5 times lower fertilizer use and frequency than those in central. In 2014, the intervention was therefore augmented in western Kenya with a treatment consisting of a 50-kg bag of high-quality fertilizer. Unlike the marketing treatment, the fertilizer treatment was randomized at the farmer level such that receipt of fertilizer varied within villages. This secondary randomization resulted in four treatment groups: *(i)* received information and a free 250-gram trial seed packs in 2013, *(ii)* received a 50-kg bag of fertilizer in 2014, *(iii)* received both the seed in 2013 and the fertilizer in 2014, and *(iv)* a control group that received no treatment. For this study we consider only the impact of the information treatment.

Two subsequent waves of data collection took place in early 2015 and early 2016, where the full household survey was re-administered (demographics, agricultural practices, and subjective beliefs). The second wave of surveys took place after households in treatment groups *(ii)* and *(iii)* had already been able to apply the fertilizer and observe the results. Additionally, a phone survey was conducted in early 2014 that elicited objective and subjective information about farmers' experiences with the sample seeds

2.2 Data

The survey instrument elicited a wide range of household demographic and agricultural information, including the histories of farmer hybrid usage, as well as plot-level seed and fertilizer usage and information on credit access. The research team also collected soil samples from the main maize field of each household, which were sent for testing at an ISO-certified laboratory in Nairobi. The soil samples provide a range of soil characteristics, including the cation exchange capacity (CEC) of the soil, a measure of the soil's ability to hold onto essential nutrients and to supply them to a crop (Jones and Jacobsen, 2005). It is widely recognized as the single best indicator of soil fertility (see for example Sanchez, 1976). CEC is particularly useful in our context, as it is very difficult to alter, and as such is not affected by past farm management practices. It is, however, related to a plot's returns to hybrid use: hybrids are more responsive to nutrients than are local maize varieties, and soils with a greater ability to hold on to nutrients will therefore show larger yield differentials between local seed varieties and hybrids.

The survey instrument also included a module that elicited farmers' subjective belief distributions over yields in the following 20 years for both (1) their current practices and (2) their preferred hybrid. For the elicitation procedure, farmers defined the support of each yield distribution by answering questions about the best and worst possible yields that they could obtain on their field.[4] Prior to the farmers placing beans to represent their subjective likelihoods, the support was discretized into five equally sized intervals by the tablets being used for data collection.

For the distribution under current practices, respondents were read the following text, and given 20 beans to allocate accordingly: "Using the same techniques as you have been for the previous 5 years, please allocate [probabilities] based on how many years out of the next 20 you think your yields will be in the intervals on your best maize field.". Prior to the farmers placing beans to represent their subjective likelihoods, the support was discretized into five equally sized intervals. Farmers were then asked to repeat the same procedure but were prompted to imagine using the hybrid seed of their choice and the optimal level of fertilizer. From these allocations, we fit a log-normal approximation for the responses and estimate the parameters of individual distributions using least squares, in particular the first and second moments of the distributions.

Additionally, respondents were asked to identify which hybrid maize seed they would choose if they had money to purchase any hybrid seed that they wanted. Due to the timing of the surveys, the baseline subjective beliefs were elicited after both the information sessions and farmers experiences with the seed packs during the 2013 season.[5] Thus, we have three post-seed-treatment belief measurements and two post-fertilizer belief measurements.

The phone survey in 2014 elicited farmers' experiences with the sample seeds, and asked respondents to evaluate the seeds' performance. The phone survey reached around 85% of the

[4]The lower bound of the interval was elicited using the following wording: "Please think of your best maize field. Imagine all the reasons why you might have a very bad maize harvest -- the worst that you can imagine! In this worst year that you can imagine, how many bags do you think that you would harvest?" The upper bound was elicited analogously.

[5]Previous studies using this data confirm equality between treatment and control on numerous variables suggesting that the randomization was successful (Tegemeo, 2014).

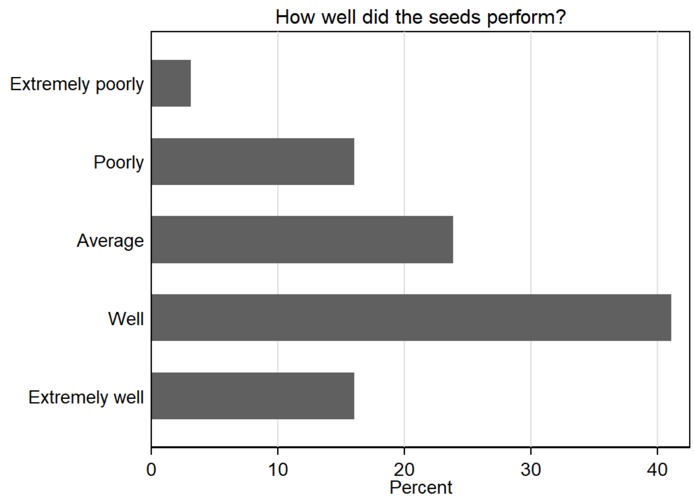


Figure 2: Seed sample pack performance

sample households, so we do not have experience data from all households. The performance measures include how much maize was harvested from the seed packs and a hypothetical question about how much maize the farmers would have harvested if they had planted their normal seeds in the same conditions (inputs, weather, etc.). These questions provide a measure of the farmers' perceptions of the efficacy of the seeds on their fields.

2.3 Descriptive statistics

Of those farmers that experimented with the seed and were reached by the phone survey, 57 percent report that the seeds performed well or extremely well (Figure 2) and 85 percent of farmers said they were likely or extremely likely to recommend the seeds to a friend (Figure 3). The subjective performance measures differ by region, with farmers in the western region reporting higher rates of above average performance (61 percent) relative to farmers in central Kenya (45 percent). Farmers were also much more likely to recommend the seeds to others in western villages; 48 percent of farmers reported they were "likely" to recommend and 40 percent were "very likely".

Table 1 shows baseline values of past hybrid and fertilizer use, credit history, as well as the proportion of households reporting planting a WSC variety in the various survey rounds. Almost one quarter of the sample did not use a hybrid in the 10 seasons preceding the baseline

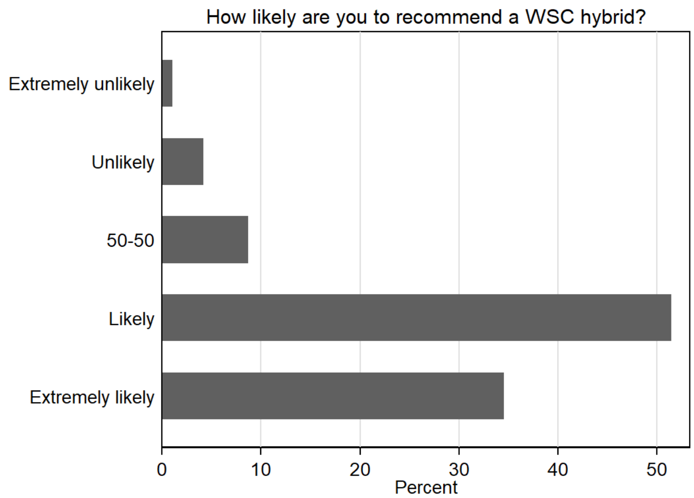


Figure 3: Likelihood of recommending seeds to friends and family

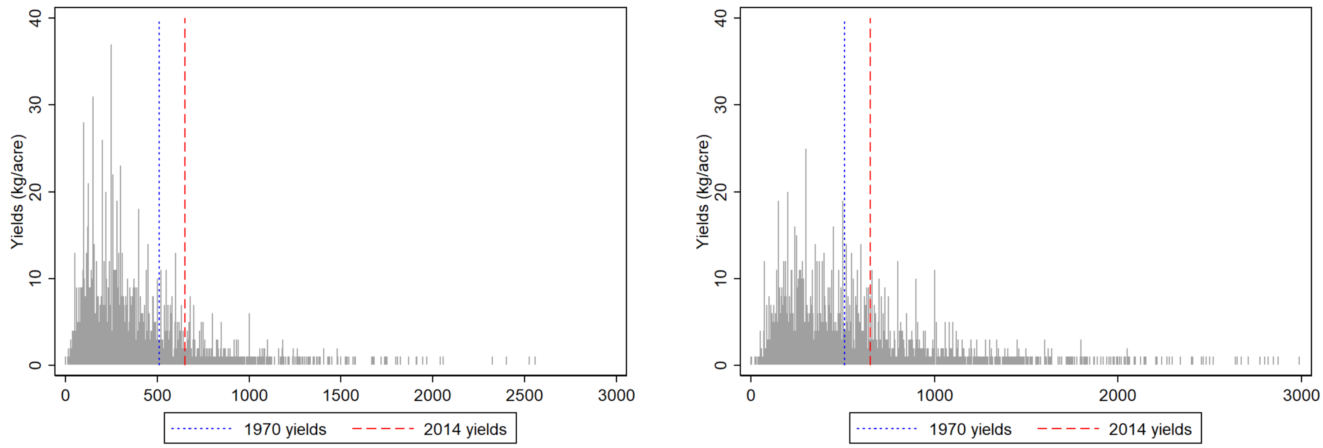
survey, and almost a third of the sample had not used fertilizer. About half the sample had at some point tried to obtain credit, and an increasing proportion of households plant a WSC hybrid in the most recent main season.

Table 1: Summary statistics in treatment villages

	Mean	**Std. Dev.**	N
Never plant hybrid	0.239	0.427	771
Never used fertilizer	0.292	0.455	771
Has tried to obtain credit	0.478	0.500	771
Planted WSC variety in round 1*	0.095	0.293	771
Planted WSC variety in round 2	0.126	0.332	771
Planted WSC variety in round 3	0.178	0.382	771

*This mean is an overestimate; some respondents appear to plant a WSC variety at baseline because they counted the sample packs.

Before exploring some relationships between yield expectations and baseline characteristics, we examine whether the levels of the expected yield beliefs of the sample farmers seem reasonable. Figure 4 displays the mean yields in our sample and compares them to FAO statistics on average maize yields in Kenya in 1970 (blue dashed line) and 2014 (red dashed line). As can be seen, the majority of farmers have lower expectations than the country average, but this is not very surprising given that the average is likely driven up by Kenya's high-potential bread basket in the Rift Valley. We can also see that the yield beliefs under farmers' preferred varieties is shifted to the right compared to the expectations under current



(a) Current practice (b) Preferred variety

Figure 4: Mean beliefs in sample

practices.

Figure 5 shows the relationship between farmers' yield beliefs given current practices, separated by region. The x-axis displays the number of seasons that a farmer reported (at baseline) having used hybrids out of the past 10 seasons. Note that most farmers in the Central region planted hybrids in all 10 seasons, while Western farmers vary much more along this dimension, with many planting hybrids in the main season only. We would expect a farmer who has planted local varieties every seasons out of the past 10 to have a lower expected status-quo yield than a farmer who has used improved inputs every season out of the past 10. Indeed, in both regions, it seems that farmers have incorporated their past hybrid use into their expectations, as greater past hybrid use is associated with higher mean current-practice yield expectations.

We now turn to our empirical strategy, in which we move away from correlations to the main focus of the paper: estimating the causal effect of the information treatment on farmer beliefs, preferences, and behavior.

3 Empirical results

In this section, we begin by examining how randomized information about the new hybrid maize variety affects individual farmers' yield beliefs, preferences and behavior. For both

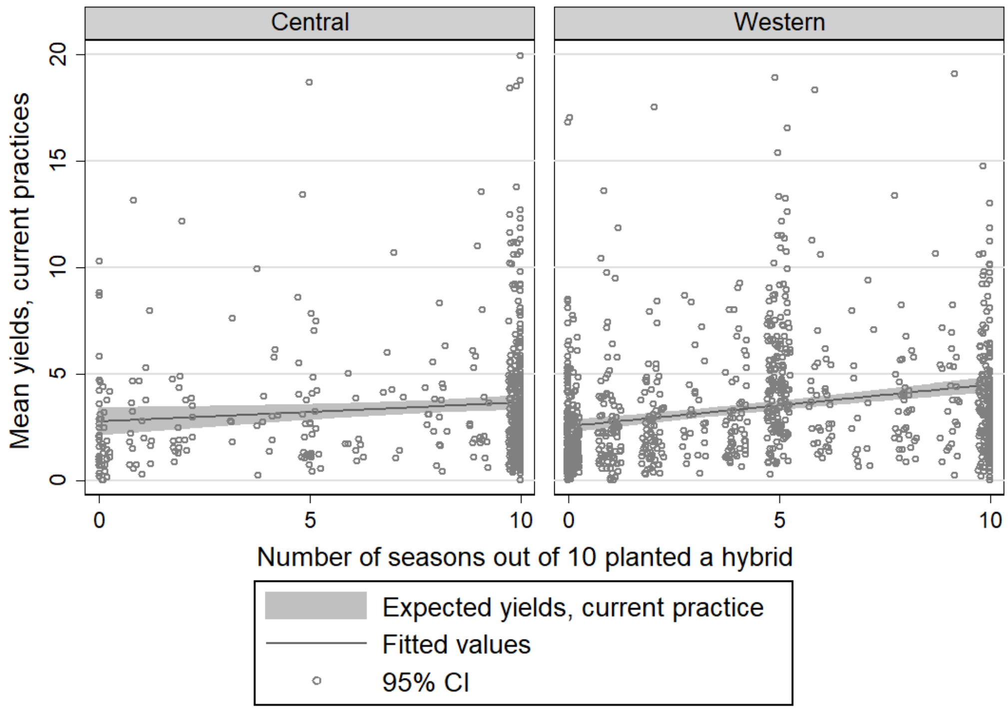


Figure 5: Expected yields vs. past hybrid use

questions, we report intention-to-treat (ITT) estimates, since selection into planting the seed pack, or applying the fertilizer, is endogenously determined by farmer characteristics. We also explore heterogeneity in the treatment effects as a function of household baseline characteristics, to examine potential mechanisms that determine who updates the most from the information innovation. In particular, we focus on previous experience with hybrids and fertilizers, since we would expect past experience to influence the strength of updating. Finally, we use an instrumental variable (Cation Exchange Capacity) for expectations, since we also expect beliefs and belief-revisions to be endogenous to regressions of planting behavior on expectations.

Table 2: Baseline balance

	(1) Control		(2) Treatment		t-test Difference
Variable	N	Mean/SE	N	Mean/SE	(1)-(2)
Maize yield	759	6.317	735	6.500	-0.183
		(0.271)		(0.294)	
No hybrid	812	0.272	771	0.245	0.027
		(0.016)		(0.016)	
Fraction hybrid	809	0.577	769	0.586	-0.009
		(0.015)		(0.016)	
No fertilizer	812	0.270	771	0.284	-0.014
		(0.016)		(0.016)	
Perceived fertility	643	1.950	724	1.902	0.048
		(0.024)		(0.022)	
Head gender	812	0.730	771	0.693	0.038*
		(0.016)		(0.017)	
Head age	812	56.094	771	54.693	1.401*
		(0.540)		(0.511)	
Head education	812	8.967	771	8.873	0.094
		(0.342)		(0.290)	
HH size	812	3.877	771	3.732	0.145
		(0.066)		(0.065)	
Credit (not apply)	812	0.420	771	0.380	0.040
		(0.017)		(0.017)	
Credit (wouldn't obtain)	812	0.139	771	0.145	-0.006
		(0.012)		(0.013)	
E(Y_b)	810	3.368	770	3.686	-0.318
		(0.112)		(0.162)	
E(Y_p)	810	5.093	770	6.388	-1.295*
		(0.153)		(0.790)	

Notes: The value displayed for t-tests are the differences in the means across the groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

3.1 Treatment effect on beliefs and behavior

First, we estimate the causal impact of the seed diffusion strategy on farmers' belief distributions with the following regression for a given outcome Y_{ic} for farmer i in cluster c:

$$Y_{ic} = \alpha + \beta T_{ic} + \epsilon_{ic} \tag{1}$$

where the outcome variables include the first and second moments of the distributions of subjective beliefs under the preferred hybrid scenario, $E[Y_p]$, and whether the farmer chose WSC as their preferred hybrid seed ($PreferWSC$). The belief distributions are in units of 100 kg/acre. The indicator variable T_{iv} equals 1 if the farmer is in a cluster that was assigned to the seed treatment and 0 otherwise. The parameter β is the coefficient of interest and provides an estimate of the treatment effect of the seed information program. The estimates are intent-to-treat (ITT) estimates of receiving seeds, since selection into actually planting the seed pack is endogenously determined by unobservable farmer characteristics. Where noted, we also include a vector of household characteristics at baseline (X_{ic}) to increase the precision of the ITT estimates.

Columns (1) - (4) of Table 3 show estimates of the effect of the seed information treatment on farmers' mean preferred-seed beliefs, and columns (5) - (8) show effects of the seed treatment on farmers' stated preferences towards WSC, i.e. the probability that they chose a WSC as their preferred seed variety. We can see that across the board, being in a treatment village increases a farmer's expected yields by between 35 and 45 kg/acre. The mean yield beliefs are 478 kg/acre, which is close to 5.3 bags/acre[6] and very similar to observed yield averages in our sample across the three rounds, implying that the seed information treatment increases farmer expected yields with their preferred hybrid variety by 7 to 9 percent. In columns (5) - (8), being exposed to the seed treatment increases individuals' likelihood of listing a WSC variety as their preferred hybrid by around 20%, i.e. doubles the probability compared to the sample mean. The estimates of the impact of the seed treatment do stay relatively stable when controls are included and there are no differences in expected yields or preferences for WSC seed by hybrid or fertilizer experience or credit. Farmers' expectations about preferred hybrid seeds do not change by experience with hybrids or fertilizer experience. These results suggest that farmers' expectations and preferences for new seeds are not driven by experience or constraints, though their adoption behavior may be. This finding could be attributed to information sharing within villages to the extent that farmers within a village adjust their beliefs based on the experiences and/or expectations of others.

[6]"Bags" are a common measure in Kenya, where each bag contains around 90 kg of maize.

Table 3: Seed treatment on mean yield beliefs and preferences: Dependent variable is averaged over three rounds

	$E(Y_p)$				Prefer WSC			
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Seed packs	0.352**	0.395*	0.429*	0.242	0.220***	0.212***	0.189***	0.243***
	(0.173)	(0.205)	(0.231)	(0.208)	(0.0358)	(0.0431)	(0.0422)	(0.0432)
Seed packs*never hybrid		-0.199				0.0275		
		(0.306)				(0.0526)		
Never plant hybrid		-0.272				-0.0399		
		(0.221)				(0.0436)		
Seed packs*never fert			-0.259				0.107	
			(0.320)				(0.0636)	
Never fertilizer			-0.246				-0.0273	
			(0.231)				(0.0412)	
Seed packs*Credit				0.230				-0.0488
				(0.229)				(0.0407)
Try credit				0.0729				0.0200
				(0.142)				(0.0325)
Constant	6.190***	4.846***	4.797***	4.660***	0.408***	-0.0314	-0.0316	-0.0439
	(0.831)	(0.756)	(0.741)	(0.790)	(0.0862)	(0.0937)	(0.0926)	(0.0908)
Observations	1,368	1,368	1,368	1,368	1,368	1,368	1,368	1,368
Rounds	All	All	All	All	All	All	All	All
Mean Dep.Var.	4.804	4.804	4.804	4.804	0.204	0.204	0.204	0.204

Controls: Gender, education, soil fertility, household size. Standard errors are clustered at the cluster level

Credit_1= Applied for credit; Credit_2 = Did not apply; would obtain if applied;

Credit_3 = Did not apply; would not obtain

*** p<0.01 ** p<0.05 * p<0.1

Table 4 presents the impacts of the effect of the seed treatment on the variance of farmers' beliefs about their preferred seed variety. The treatment has little impact on the variance of farmers' beliefs. Generally, more information should increase the precision of agents' priors. However, the experimentation with a small pack of seeds may not have been sufficient to change the precision of farmers' in this context, despite increasing their expectations. However, we would expect accumulated experience over time to decrease farmers' uncertainty over hybrid usage. Column (3) suggests that there is heterogeneity in the variance of farmers' beliefs by fertilizer usage, such that farmers that have no history of fertilizer usage have 25 percent higher variance in their beliefs relative to the mean.

Next, we examine whether the information treatment has spillovers onto other hybrid varieties. In a setting where a substantial proportion of farmers have never tried a hybrid variety, it is possible that farmers may update their beliefs about hybrids *in general*, and therefore try other varieties.[7] In Table 5, all regressions are estimated using a linear probability model. In columns (1) - (4), the likelihood that households actually plant a hybrid does not change overall in treatment villages. However, the seed treatment increases the likelihood of adoption amongst farmers that had no experience with hybrids prior to the treatment (13.9 percent increase). Despite not differentially increasing expectations amongst farmers with no hybrid experience (Table 3), the seed pack may have provided the initial experience needed for non-experienced farmers to adopt hybrids over a larger area. In columns (5) - (8), being in a village that received the information treatment roughly doubles the likelihood of planting a WSC hybrid regardless of hybrid or fertilizer history and credit constraints. Thus, seed treatment seems to induce a substitution of other hybrids for WSC in treatment villages and encourage overall hybrid adoption amongst those with no previous hybrid experience. Further, we see that farmers who never planted a hybrid prior to the baseline survey remain substantially less likely to plant a hybrid in subsequent years, and that a lack of fertilizer usage decreases the likelihood of planting any hybrid.

[7] Another reason why farmers may have decided to try a different variety was that between the first and second survey rounds, the seed company encountered production and distribution difficulties, such that more than half the sample stated that they did not know where to buy the varieties if they wanted to.

3.2 Spillovers

We next turn to treatment villages only, and examine whether farmers update asymmetrically with respect to good and bad news, as well as whether they update differently based on their own evaluations of the seed's performance relative to other villagers' experiences. In Table 6, we report regressions of individuals' expected yields and preference for WSC seeds based on their own evaluation of the seed samples' performance, as well as on evaluations of other villagers. Columns (1), (3) and (4) suggest that an own-evaluation of the sample packs that is "excellent" or "very good" is associated with a roughly 100-kg increase in the mean expected yields under a hybrid. Rating the seeds below average is associated with a decrease of around 90 kg under preferred hybrids. This suggests that farmers update only slightly more strongly with respect to good news than to bad news – an effect that might be positive in the current context

However, in column (2), when we control for the average ratings of other villagers, the updating looks much more asymmetric. Conditional on other farmers' ratings, farmers rate positive experiences almost double their own negative experiences. When it comes to other farmers in the village, the respondents seem to update much more strongly in response to negative ratings by other farmers: if the proportion of other farmers who rate the seed negatively went from 0 to 1, it would result in a 200-kg decrease in the average expected yield for preferred hybrids, compared to a mean of 520 kg/acre! These results are also robust to including controls for past experience with hybrids (results not reported).

When we look at the effect of subjective evaluations on the probability of preferring a WSC hybrid over all other options (columns (5) - (8)), we see a slightly different pattern: own-evaluations still play an important role, and the estimate of this effect remains stable after controlling for the evaluations of other farmers. But the effect of negative own-ratings is insignificant and point estimate is even sometimes positive. Further, the number of recommenders in a farmer's village increases the likelihood of preferring WSC, but the effect is small.

In contrast, the impacts of own positive experiences on actual planting behavior is much larger than own negative experiences. While farmers' beliefs seem to update symmetrically in response to good and bad news, their planting behavior is influenced primarily by positive news. Having an above average experience with the seed packs increases the likelihood of planting between 7.5 and 9.3 percent in columns (1)-(4). The number and ratio of other villagers who state that they would recommend WSC seeds has no effect on planting hybrids but an increase in one recommender increases the likelihood of planting WSC seed by 2 percent. The effects of own experiences on the probability of planting a WSC hybrid appear to go in the expected direction, but since the sample sizes have been reduced quite substantially, they are imprecisely estimated.

3.3 IV results

Ultimately, we are interested in understanding the extent to which expected yields influence farmer behavior. In particular, we are interested in seeing whether farmer beliefs affect technology adoption. There are of course many reasons to believe that individuals' expectations, as well as their propensity to update their beliefs, might be endogenous to their adoption of improved technologies. In order to understand whether revisions to expected yields affect farmer behaviors, we therefore need an instrument for expectations. We argue that the Cation Exchange Capacity (CEC) of a farmer's maize field constitutes a credible instrument for respondents' expectations about hybrids. First, we believe that CEC fulfills the exclusion criterion as it is essentially an aspect of farmers soils that cannot be affected by farm management practices (as described in more detail in Section 2). CEC is therefore highly unlikely to be affected by the types of farmer characteristics (whether observed or unobserved) that we usually worry might also directly affect adoption behavior. CEC is also a relevant instrument as it influences a plot's returns to hybrid use: hybrids are more responsive to nutrients than are local maize varieties, and soils with a greater ability to hold on to nutrients will therefore show larger yield differentials between local seed varieties and hybrids. Table 8 shows the results of instrumental variables regressions, where CEC is used to instrument for farmers' beliefs regarding hybrid yields.[8]

[8]The strength of the first-stage regressions is quite low, and a careful reader might worry about bias resulting from weak instruments. The results are very similar if we use only CEC as an instrument, and just-identified IV with a weak instrument is centered at the truth – while overidentified 2SLS is biased toward OLS (Angrist and Pischke, 2009). Bias with a just-identified model is therefore typically less serious, since if our just-identified IV were seriously biased, we would expect very large second-stage standard errors.

We can see that beliefs do seem to carry through to action: the expected mean yield of a farmer's preferred hybrid seems to positively affect their probability of planting a hybrid in general, as well as their probability of planting a WSC variety. Columns (1) - (2) and (5) - (6) present results for the effect of farmer beliefs about their preferred variety, while columns (3) - (4) and (7) - (8) show instead the difference between beliefs about improved and baseline varieties. The estimated coefficients in columns (1) - (2) and (5) - (6) are quite small, but when we look at the effect of the perceived incremental return from planting a hybrid, relative to planting according to current practices, $E(Y_p) - E(Y_b)$, we see substantial impacts on both outcome variables. An increase in the yield differential of 100 kg/acre is associated with a 73% increase in the probability of planting a hybrid, and an 18 percent increase in the probability of planting a WSC hybrid. Note that the baseline value of $E(Y_p) - E(Y_b)$ is roughly 180 kg/acre, so an increase of 100 kg/acre would be quite a large change in expectations.

4 Conclusion

We document considerable effects of an information intervention related to a new agricultural technology on farmer beliefs, preferences, and behaviors. Farmers have baseline beliefs that are in line with average observed yields in the region, and these beliefs correlate with farmers' past experience with improved agricultural technologies. Furthermore, farmers' updating behavior is logical and consistent with a small degree of asymmetric updating (weighing good news more strongly than bad news), but we also find that farmers seem to place heavier weight on bad news than on good news when it is coming from other community members.

Instrumental variable regressions further show that these belief revisions can also translate into behavioral change: farmers with higher expected returns to hybrids, as instrumented by CEC, a soil quality measure that is correlated with a plot's suitability for hybrids, are more likely to plant a hybrid variety the subsequent season.

These findings have important implications both for policy and for the literature on belief updating. Our data suggest that this population has baseline beliefs that are downwardly biased, but that they update their expectations and behaviors in response to a one-time, relatively low-cost information intervention. The literature on information interventions has reported mixed results, but our results suggest that learning interventions in developing-country agriculture may have greater promise than often believed. The results seem to vary relatively little with respect to baseline characteristics, suggesting that information updating is something that this sample of poor, rural farmers are able to do consistently and in accordance with economic theory.

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Table 4: Seed treatment on variance of yield beliefs: Dependent variable is averaged over three rounds

	$V(Y_p)$			
Variables	(1)	(2)	(3)	(4)
Seed packs	0.216	0.0555	0.0417	0.615**
	(0.248)	(0.304)	(0.338)	(0.292)
$E(Y_p)$	2.399***	2.404***	2.410***	2.408***
	(0.180)	(0.179)	(0.180)	(0.179)
Seed packs*never hybrid		0.639		
		(0.661)		
Never plant hybrid		0.103		
		(0.373)		
Seed packs*never fert			0.530	
			(0.645)	
Never fertilizer			1.329**	
			(0.614)	
Seed packs*Credit				-0.851
				(0.506)
Credit				-0.593
				(0.402)
Constant	-5.509***	-1.789	-1.916	-1.055
	(1.836)	(1.651)	(1.640)	(1.765)
Observations	1,368	1,368	1,368	1,368
Rounds	All	All	All	All
Mean Dep.Var.	4.955	4.955	4.955	4.955

Controls: Gender, education, soil fertility, hh size
Standard errors are clustered at the cluster level.
Credit1 = Applied for credit, Credit2 = No apply/Would obtain,
Credit3 = No apply/Would not obtain
*** $p<0.01$ ** $p<0.05$ * $p<0.1$

Table 5: Probability of planting any hybrid or a WSC variety, pooled across three rounds and interacted with hybrid, fertilizer, and credit history

	Plant Hybrid				Plant WSC			
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Seed packs	0.0291	-0.0140	0.00227	0.00589	0.197***	0.197***	0.184***	0.178***
	(0.0351)	(0.0169)	(0.0126)	(0.0336)	(0.0370)	(0.0453)	(0.0462)	(0.0405)
Never fertilizer			-0.245***				-0.0587*	
			(0.0693)				(0.0325)	
Seed packs*never hybrid		0.138*				-0.00563		
		(0.0789)				(0.0578)		
Never plant hybrid		-0.347***				-0.0587		
		(0.0604)				(0.0372)		
Seed packs*never fert			0.104				0.0471	
			(0.0982)				(0.0670)	
Seed packs*Credit				0.0347				0.0353
				(0.0301)				(0.0379)
Try credit				-0.00969				-0.0112
				(0.0193)				(0.0251)
Constant	0.961***	1.045***	0.993***	1.022***	0.0463	0.0598	0.0555	0.0595
	(0.0677)	(0.0591)	(0.0528)	(0.0619)	(0.0974)	(0.0957)	(0.0953)	(0.0999)
Observations	1,368	1,368	1,368	1,368	1,368	1,368	1,368	1,368
Round	All	All	All	All	All	All	All	All
Mean Dep.Var.	0.843	0.843	0.843	0.843	0.178	0.178	0.178	0.178

Controls: Gender, education, soil fertility, household size. Standard errors are clustered at the cluster level

Credit_1= Applied for credit; Credit_2 = Did not apply; would obtain if applied;

Credit_3 = Did not apply; would not obtain

*** p<0.01 ** p<0.05 * p<0.1

Table 6: Seed treatment on expected yields: dependent variable is averaged over all three rounds (treatment sample)

	$E(Y_p)$				Pref WSC			
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Own above average	1.061***	0.974***	1.078***	1.043***	0.0930**	0.108**	0.0969**	0.0938**
	(0.324)	(0.281)	(0.326)	(0.312)	(0.0432)	(0.0417)	(0.0433)	(0.0436)
Own below average	-0.965**	-0.551*	-0.928**	-0.898**	-0.00391	-0.0156	0.00492	-0.00670
	(0.381)	(0.317)	(0.386)	(0.381)	(0.0771)	(0.0667)	(0.0771)	(0.0778)
Ratio above average		-0.190				-0.0928		
		(0.941)				(0.121)		
Ratio below average		-2.701**				0.0293		
		(1.062)				(0.190)		
# Recommenders			0.0366				0.00869***	
			(0.0258)				(0.00301)	
Ratio recommend				1.397				-0.0578
				(1.851)				(0.144)
Constant	5.356***	6.179***	5.030***	4.304**	-0.0186	-0.00244	-0.0960	0.0249
	(1.169)	(1.221)	(1.146)	(1.960)	(0.199)	(0.222)	(0.203)	(0.227)
Observations	529	529	529	529	529	529	529	529
Rounds	All	All	All	All	All	All	All	All
Mean Dep.Var.	5.277	5.277	5.277	5.277	0.372	0.372	0.372	0.372

Controls: Gender, education, soil fertility, household size.

Credit_1= Applied for credit; Credit_2 = Did not apply; would obtain if applied;

Credit_3 = Did not apply; would not obtain

Standard errors are clustered at the cluster level.

*** p<0.01 ** p<0.05 * p<0.1

Table 7: Probability of choosing a WSC hybrid as preferred hybrid (Prefer WSC) and planting a WSC variety (Plant WSC), pooled across three rounds for treatment sample

	Plant Hybrid				Plant WSC			
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
								Own above average
0.0910**	0.0747**	0.0933**	0.0896**	0.0368	0.0490	0.0471	0.0349	
	(0.0371)	(0.0346)	(0.0361)	(0.0367)	(0.0700)	(0.0652)	(0.0679)	(0.0685)
Own below average	-0.0181	0.00167	-0.0129	-0.0134	-0.0723	-0.0641	-0.0491	-0.0655
	(0.0501)	(0.0298)	(0.0525)	(0.0513)	(0.0725)	(0.0626)	(0.0593)	(0.0717)
Ratio above average		0.0874				-0.115		
		(0.111)				(0.130)		
Ratio below average		-0.0832				-0.107		
		(0.147)				(0.216)		
# Recommenders			0.00511				0.0229***	
			(0.00324)				(0.00411)	
Ratio recommend				0.0977				0.141
				(0.122)				(0.160)
Constant	0.928***	0.929***	0.882***	0.854***	0.268	0.329	0.0645	0.162
	(0.0919)	(0.123)	(0.0966)	(0.118)	(0.231)	(0.245)	(0.221)	(0.240)
Observations	529	529	529	529	529	529	529	529
Round	All	All	All	All	All	All	All	All
Mean Dep.Var.	0.894	0.894	0.894	0.894	0.335	0.335	0.335	0.335

Controls: Gender, education, soil fertility, household size.

Credit_1= Applied for credit; Credit_2 = Did not apply; would obtain if applied;

Credit_3 = Did not apply; would not obtain

Standard errors are clustered at the cluster level.

*** p<0.01 ** p<0.05 * p<0.1

Table 8: Impacts of expected yields in past season on probability of planting western seed in upcoming season by western. Instruments with CEC and its square

	Plant Hybrid				Plant WSC			
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$E(Y_p)_{T-1}$	0.15**	0.19***			0.033	0.083***		
	(0.062)	(0.042)			(0.028)	(0.027)		
$E(Y_p)_{T-1} - E(Y_b)_{T-1}$			0.40	0.46***			0.084	0.20**
			(0.27)	(0.17)			(0.11)	(0.091)
Western	-0.17**	-0.22***	-0.11	-0.23***	0.11***	0.14***	0.12***	0.14***
	(0.079)	(0.077)	(0.13)	(0.084)	(0.036)	(0.049)	(0.045)	(0.045)
Gender	-0.045	0.0047	-0.054	0.076	0.0043	0.018	0.0036	0.049
	(0.053)	(0.044)	(0.082)	(0.064)	(0.018)	(0.030)	(0.022)	(0.036)
Age	0.000046	0.0019	-0.0013	0.0017	0.00038	0.00092	0.000048	0.00087
	(0.0021)	(0.0016)	(0.0026)	(0.0020)	(0.00059)	(0.00077)	(0.00060)	(0.00099)
Constant	0.12	-0.13	0.18	0.010	-0.18	-0.40***	-0.16	-0.35*
	(0.35)	(0.25)	(0.53)	(0.36)	(0.14)	(0.14)	(0.19)	(0.18)
N	1576	1576	1576	1576	1576	1576	1576	1576
F-stat	2.12	4.82	1.34	2.41	2.12	4.82	1.34	2.41
Round	2	3	2	3	2	3	2	3

Controls: Gender, education, soil fertility, household size.

$Credit_1$= Applied for credit; $Credit_2$ = Did not apply; would obtain if applied;

$Credit_3$ = Did not apply; would not obtain

Standard errors are clustered at the cluster level.

*** p<0.01 ** p<0.05 * p<0.1