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CAN MARKETS SUPPORT SMALLHOLDER ADOPTION OF A FOOD SAFETY TECHNOLOGY?

Aflasafe in Kenya

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1. INTRODUCTION

Food safety has become an important precondition for access to global food markets and increasingly for high-value domestic markets in developing countries (Ashraf, Gine and Karlan, 2009; Van Beuningen and Knorringa, 2009). At the same time, food-borne pathogens and toxins exact a significant health toll in developing countries (WHO, 2015), particularly among the poorest (Leroy, Wang, and Jones, 2015; Hoffmann and Moser, 2017).

Contamination with fungal toxins (mycotoxins) is a major food safety concern in tropical regions. Chronic exposure to aflatoxin, a common mycotoxin in maize and groundnut, is known to cause cancer and liver damage (Strosnider et al., 2006). Very high levels of exposure to aflatoxin can cause jaundice, permanent liver damage, and death. In Kenya, cases of acute aflatoxin poisoning have been linked to the consumption of maize produced and stored by households in Eastern Kenya, recognized as a global aflatoxin hotspot (Daniel et al., 2011). Evidence is emerging that aflatoxin plays a role in childhood stunting (Gong et al., 2004; Turner et al., 2007; Hoffmann et al., 2018). In Africa, widespread contamination of maize and groundnuts with the toxin limits export opportunities (Munasib and Roy, 2011). Domestic food processors vulnerable to reputation effects and international humanitarian organizations required to adhere to global standards in the food they distribute avoid sourcing from aflatoxin-affected regions (Hoffmann and Moser, 2017), and import inputs at considerable cost from the Americas (personal communication, Carly Edwards, Project Peanut Butter, March 28, 2018).

Effective technologies to reduce food safety hazards in farm produce, including contamination with aflatoxin, are available but face several barriers to adoption. First, food safety is a hidden trait. Observation of contaminants typically requires specialized tests, which are often costly relative to the value of farm produce. In the case of aflatoxin, a single test costs on the order of US $10 – up to half the cost of the typical value of maize grains sold by smallholder farmers in at a time.[1] Inefficiencies in output markets characterized by multiple intermediaries exacerbate informational inefficiencies since information asymmetries arise at each transaction, preventing pass-through of incentives for food safety (Fafchamps et al., 2008).

Another barrier to adoption is production risk. Many food safety technologies are applied during the production process, before the outcome of this process is observed. In a stochastic agricultural production function, any costly input increases the variability of farm profit (Just and Pope, 1978). In the case of low-income populations engaged in rainfed agriculture, the resulting risk to consumption constitutes an important impediment to technology adoption (Rosenzweig and Binswanger, 1993; Dercon and Christiansen, 2011; Emerick et al, 2016). One of the most effective tools available to combat aflatoxin, the biocontrol product Aflasafe, must applied before maize flowers, well before yield is observed.

[1] The median seasonal sale volume in the counties of Kenya where this research was conducted is 100 KG (Hoffmann and Jones, 2018). Beyond the cost of testing supplies, tests should be executed by an experienced technician and compared regularly against results using a reference material to obtain reliable results.

Several recent studies have tested impact of making rainfall index-based insurance products available to farmers in developing countries. These generally find a strong impact on the adoption of more profitable, but rainfall-sensitive technologies (Mobarak and Rosenzweig, 2013; Karlan et al, 2014; Cole et al, 2017). Such impacts can especially exist if uninsured risks are large and well-covered by the insurance (Carter et al, 2016). Yet, demand for rainfall index insurance has often remained weak. An up-front investment in insurance – an unfamiliar financial product with uncertain return, both because the conditions required to trigger a payout may not be met, and because of perceived risk that the insurance provider may not honor the contract if it is – is apparently not attractive to many farmers in these settings (Cole et al, 2013). This results in an apparent contradiction, in which farmers are, on average, better off when they are effectively insured against risk, but most don't purchase insurance when given a choice.

The main clients of ACRE Africa, a major rainfall index insurance service provider in Kenya, are agricultural input companies that bundle insurance with inputs such as seeds (personal communication, Joseph Chege, July 6, 2017). While a purely rational model of behavior predicts that forcing farmers who wish to buy an input to also insure their purchase against rainfall risk should decrease demand for the input, bundling could potentially increase input demand if the decision is affected by framing effects. Specifically, a higher price for the input may be less salient to the decision-maker than a discrete stand-alone price for the insurance. This is especially true if the consumer has no reference point for the 'normal' price of the input.

In this paper, we test the impact of a simulated market premium for food safety, and of bundling rainfall insurance with an aflatoxin-reducing technology (Aflasafe KE01), on smallholder farmers' adoption of this technology. To identify these impacts, we conducted a randomized trial through which farmers in one of the most aflatoxin-affected regions in the world were given the opportunity to purchase Aflasafe under experimentally varied market conditions. Half of 152 pre-existing producer groups were assigned to a market linkage treatment and offered a premium price for the maize they aggregated if it conformed to the East African aflatoxin standard. The market linkage treatment was cross-cut with a bundled insurance treatment, in which Aflasafe could only be purchased together with an actuarily fair rainfall index insurance product designed to insure against maize losses due to unfavorable weather conditions during the growing period. Farmers not assigned to the bundled insurance treatment who purchased Aflasafe were able to purchase the same insurance separately.

We find that the price premium, which was set to a modest 5% of the value of maize, did not affect the extensive margin of adoption, suggesting that farmers who purchased the product used it first on maize produced for their own consumption. We do, however, see a strong positive impact on the intensive margin of adoption. Farmers who were offered the food safety premium purchased nearly twice as much Aflasafe than those not given this opportunity. Bundling rainfall insurance with Aflasafe did not increase adoption of the biocontrol product, nor did it decrease adoption. This result may be explained by the fact that 75% of farmers in the non-bundled treatment arm chose to buy the insurance.

The food safety technology

Aflasafe is a biocontrol product that uses native strains of the Aspergillus fungus that do not produce toxins to outcompete toxigenic strains. Aflasafe has been shown in farmer field trials to reduce aflatoxin contamination by between 80% and 99% (Bandyopadhyay et al., 2016). Treatment with Aflasafe protects crops throughout the growing cycle and storage period, with no impact on the overall level of fungal colonization or crop yields (Cotty et al., 2007). Aflatoxin biocontrol products have been used on food crops in the United States for over 15 years.

The first African country to register an aflatoxin biocontrol product was Nigeria. There, the main buyers of Aflasafe are poultry feed processors, who provide the input to farmers they contract to grow maize (aflatoxin impedes weight gain and increases mortality among poultry).2 Aflasafe KE01 was approved by the Kenyan government for general use in June 2015, and domestic manufacturing began in 2017. The cost to produce one kg of Aflasafe at scale ranges between US $0.7 and $1.2 depending on currency exchange rates and price of materials (Bandyopadhyay et al., 2016). Due to the small volume produced in Kenya, the current price of Aflasafe there is US $1.6.

The mean aflatoxin level in samples collected by one of the authors for a separate study in the same study region in 2015, when aflatoxin contamination was considered moderate, was 17 ppb, 70% higher than the maximum allowable level in Kenya. In 2010, recognized as an aflatoxin outbreak year, the mean level of contamination was 47 ppb, 4.7 times the legal limit (Mutiga et al., 2014).

[2] See http://agresults.org/uploads/files/20141211_Nigeria_Aflasafe_Pilot_Overview.pdf

In both years, results from field trials cited above indicate that treating fields with Aflasafe would have brought the average level of contamination into the legal range.3

The premium for aflatoxin-safe maize in Kenya

The informal markets to which most maize farmers in Kenya sell do not reward unobservable quality (Hoffmann et al., 2013). However, a growing number of maize millers in the formal sector do test for aflatoxin at purchase and reject maize that does not conform to the regulatory standard. These millers offer a significant premium above the spot market price of maize in the informal market. For example, on the same day in February 2015, Unga Ltd.'s Eldoret plant was paying 2200 Kenyan Shillings (KSh) - approximately $22 US - for a 90 kg bag of maize, while the price at the open-air market in Eldoret was 1700 KSh. To obtain a premium price, several quality characteristics must be met: maize must be at or below 13.5% moisture content; it must conform to grading standards for the proportion of foreign matter, broken, damaged, and discolored kernels; and it must contain total aflatoxins below the regulatory standard. Farmers are able to meet most of these criteria through adequate drying and removal of sub-standard grains and other particles. The exception is aflatoxin, which may be present without any visible sign of contamination.

Transportation costs to existing premium markets from the study region (Meru, Tharaka-Nithi and Embu counties) are prohibitive in most years. Local millers in this region do not to our knowledge screen for aflatoxin, but one maize wholesaler does test for certain buyers, and has recently launched a maize flour product. As disposable incomes and concern over food safety grow, and government enforcement of existing regulations strengthens, it is reasonable to expect that that a local premium will emerge. However, the premium paid by regional millers is likely to be lower than that offered by the miller referenced above, which produces perhaps the two best-known brands in the country, including the most expensive. Nairobi-based millers in the next quality tier offer a premium of between 200-250 KSH per 90 kg bag over the informal market. We propose that a conservative estimate of the premium farmers in the study region could expect to receive from a regional miller for aflatoxin-safe maize, accounting for the lower spending power of consumers in this market, is 100 KSH per bag. This is the aflatoxin safety premium we offer to farmers in the market linkage treatment.

We set the cost of Aflasafe in the study to 80 KSH (US $0.78) per kg; this lies within the range of production costs and also takes into account the government of Kenya's expressed support for a partial subsidy targeted to smallholders. Together with rainfall insurance, which most farmers purchased when given the choice (and those offered the Aflasafe plus insurance bundle had no choice but to purchase), the cost per kg was 100 KSH (US $0.97). Table 1 shows summary statistics based on data collected at baseline, of the land farmers planned to plant with maize in the coming season and their expectations of the resulting harvest under normal, poor, and very good conditions. The amount of maize farmers expected to store for household consumption under a normal harvest, and the amount sold (assumed to be any maize not retained for household consumption) are also shown.

Table 1. Maize production and sales expectations at baseline

	N	Mean	Median	SD
Total land under maize this season (acre)	892	1.68	1.00	1.30
Expected harvest if season is normal (kg)	892	925	500	1150
Expected harvest if season is poor (kg)	892	367	180	609
Expected harvest if season is very good (kg)	891	1431	900	1524
Expected maize harvest this season (kg)	891	1251	900	1338
Amount stored for family consumption, normal harvest (kg)	892	283	225	213
Amount sold from a normal harvest (kg)	892	630	270	998

Note: Variables are winsorized at the 99th percentile

Dividing the mean of farmers' expected harvest under a normal year by the mean acreage under maize implies an average expected yield of 551 kg per acre.4 At this level of yield, the cost of Aflasafe per 90-kg bag (including rainfall insurance) is 65 KSH (US $0.64). With a premium of 100 KSH per bag, and mean household consumption of 283 kg, we can calculate the mean one-season return on

[3] The mean level of contamination (as opposed to the probability of non-compliance for a particular farmer) is relevant both from an economic and health perspective, since most of the health burden of aflatoxin arises though cumulative exposure to moderate levels of the toxin over time, and because maize is tested by processors in large lots.

[4] We estimate mean yield as the ratio of the means rather than the mean of the ratios because some very low values of the area planted combined with large harvests result in implausible values.

investment (ROI) to Aflasafe. The ROI is equal to the amount of maize sold, times the price premium, minus the cost of Aflasafe, divided by the cost of Aflasafe: 36% at the mean.5 Using median sales and yield values, the ROI is lower, at 12.5%.

Because the cost of testing for aflatoxin (and other food safety hazards) is high relative to the value of produce sold by the typical smallholder farmer, access to a food safety premium requires that maize is aggregated prior to testing. This can be done through producer groups, which are common in Kenya and throughout sub-Saharan Africa. These groups may be formed by external actors as a platform for providing agricultural training and extension, or by the farmers themselves to aggregate their demand for inputs or their produce and reduce transaction costs or obtain better prices. Farmers in such groups who sell to markets with food safety requirements have a strong incentive to ensure that others in the group treat their fields, analogous to a joint liability lending model. While there are many examples of group-level certification for export or other voluntary standards (IFOAM, n.d.; NACA, 2011; GlobalG.A.P., 2013, localg.a.p., 2014), and theoretical work suggests that these can be efficient (Saak, 2015), the literature on the efficacy of such schemes is thin (Preißel and Reckling, 2010; Auer, 2012; Marschke and Wilkings, 2014).

2. STUDY DESIGN

2.1 Population and sample

The population for this study consists of maize farmers who are members of existing farmer groups in Meru, Embu and Tharaka Nithi counties, Kenya. The three counties fall in the Eastern region of Kenya, and are known for their high levels of aflatoxin contamination. A list of approximately 250 farmer groups in the study area was acquired through the Cereal Growers' Association (CGA), a national member-based farmer organization, and the Ministries of Agriculture in the three counties. From April to August 2017, 224 groups were visited and lists of their members were obtained.6 From these 224 groups, we selected 152 groups into our experiment in a way that minimized the baseline differences in groups assigned to the two insurance conditions. This procedure is further discussed in Section 2.5.2, Rainfall index insurance treatments.

2.2 Training and sales

All 152 groups in our experiment were given information on the benefits of Aflasafe and instructions on its use. This was done through two rounds of training, in which all the group members were invited for a half day meeting. The first round of training took place in September-October 2017, the beginning of the main maize season in the study area. During these meetings, group members were given information on the use of Aflasafe and the role of rainfall index insurance in insuring Aflasafe against weather related shocks. In addition, some of the groups were told they could earn a premium price of 100 KSH per bag of maize grown using Aflasafe. They were informed that they could only purchase the Aflasafe (and consequently the insurance) through the project as it was not available in the study area.

A second round of training was conducted in November and early December, a few weeks after planting and just before the time at which Aflasafe should be applied. During these meetings, group members were given instructions on how to use Aflasafe and how to activate the rainfall insurance. A demonstration of the Aflasafe application process was conducted on one member's farm. At the end of the meeting, those present were given an opportunity to purchase Aflasafe and the rainfall index insurance. Aflasafe was offered in packages of 4 kg, a quantity sufficient to treat one acre of land. Insurance vouchers were packed inside a subset of the packets of Aflasafe, and a sticker was affixed to exterior of the packet indicating its inclusion. Farmers who wished to purchase amounts less than 4 kg were requested to pair up with other group members who needed similar amounts and asked to purchase one packet and share amongst themselves7. Farmers who wished to purchase Aflasafe later were given a chance to do so through a subsequent sales visit by the project staff.

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[5] There is a chance that a given farmer's or producer group's maize tests above the standard despite applying Aflasafe. We took the same approach in this study. Producer groups whose maize tested above the limit for aflatoxin could still earn the aflatoxin safety premium if their maize tested positive the fungal strains of Aflasafe. This test requires laboratory equipment and is more costly, so it could not be applied as the primary requirement to obtain the premium price.

[6] Some of the groups in the initial list were members of the same Community Based Organization(CBO). In such cases, only one group per CBO was visited for our study.

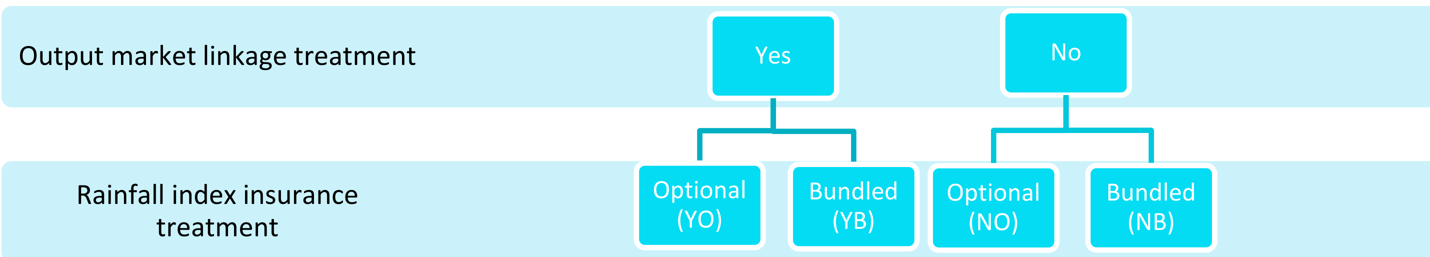
[7] Farmers who paired up were recorded separately, as independent entries in our Aflasafe sales data sheets, showing their respective amounts depending on the amount of money paid by each of the farmer.

Both rounds of meetings were conducted by trainers employed by the CGA. CGA trainers had been instructed on the use of Aflasafe by the International Institute of Tropical Agriculture (IITA), which supplied the Aflasafe, and on activation of the rainfall index insurance by ACRE Africa, the rainfall index insurance provider.

2.3. Experimental design

The experimental design is illustrated in Figure 1. All 152 groups in the experiment were given the opportunity to purchase Aflasafe and training on its use. Half of these groups were randomly assigned to receive a premium price for safe maize (output market linkage). The market linkage treatment was crossed with two rainfall insurance treatment conditions: groups assigned to a *Bundled* condition were only offered Aflasafe together with the insurance; those assigned to an *Optional* condition were offered the option to buy Aflasafe either with or without the insurance. Hence, in total there were four treatment groups (YB, YO, NB, and NO).

Figure 1. Graphical representation of the experimental design



2.3.1 Output market linkage treatment

During the initial round of training, groups assigned to the output market linkage treatment were promised a bonus of 100 KSH per bag for maize grown using Aflasafe. The bonus was to be paid shortly after harvest. Members who purchased Aflasafe and wanted to sell their maize through the project would aggregate their maize at a central place to be identified by the group members. A rapid qualitative aflatoxin test would be conducted on the aggregated maize to check if the maize had aflatoxin levels higher than the East African limit (10 ppb). Farmers were informed that any aggregated maize that contained levels higher than 10 ppb would not qualify for the bonus. They were advised to record the number of members who purchased Aflasafe in their group and the amount purchased by each member, and to ensure that only treated maize was aggregated for testing. Aggregation of maize and payment of the bonus took place in February-March 2018, at the end of the harvest season.

2.3.2 Rainfall index insurance treatments

A rainfall index insurance product was designed by ACRE Africa, a major rainfall index insurance provider in Kenya, to insure against maize losses due to unfavorable rainfall conditions during the growing period. Farmers were instructed on how to activate their insurance contract via SMS using a code on a scratch card provided in the insured Aflasafe. They were told to complete the activation on the farm where the Aflasafe would be applied, at the time of application.8 The time and location of activation were automatically recorded in a database maintained by ACRE Africa. Based on these, insurance payments could be triggered in each of the three maize growing stages: for drought during the vegetative and flowering stages, and for excessive rainfall during the ripening stage. The insurance payout was increasing in the gap between actual and ideal conditions. The insured value was set equal to the farmer's cost of Aflasafe plus insurance. The expected payout, based on historical rainfall data, was 20% of the insured value. Payouts were made automatically via the widely-used Kenyan mobile money platform MPesa.

Product development and administrative costs of the insurance were subsidized through study funds, so that farmers paid an actuarially fair premium of 20% of total insured value. The price of the bundle of a 4 kg package of Aflasafe with insurance was thus

[8] For the cases where farmers purchased less than one packet of Aflasafe by paring up with someone else, only one of the farmers could activate the insurance card. The farmer who activated the card received the payout and reimbursed the other farmer (farmers) depending on how much Aflasafe (and insurance) they had paid for out of the 4 kg packet.

320+.2*400=400 KSH. In the bundled insurance treatment, farmers were only offered the opportunity to buy a package of Aflasafe with an insurance scratch card included for the price of 400 KSH. In the optional insurance treatment, farmers were given the choice between a package of Aflasafe without insurance for 320 KSH and a package of Aflasafe with an insurance scratch card for the price of 400 KSH.

To support a better understanding of the insurance product by farmers, the insurance product was consistently referred to as a “money-back guarantee” in all communications to farmers.

2.4 Data

A short survey of all 224 farmer groups on the initial list was conducted during meetings with these groups in April-August 2017 for the purposes of sample selection, stratification, and balance checks. Data on each group’s geographical location, as well as their members’ familiarity with weather insurance, awareness of aflatoxin, use of agricultural inputs, and levels of maize production and marketing were collected. Lists of the groups’ members, indicating whether each member was present during the initial meeting or not, were also obtained.

After selecting 152 groups into the study, baseline survey data was collected from each of these. Baseline data collection took place in September-October 2017, just before the first round of training. Data was collected both at the individual farmer level and at the farmer group level. This data was used to generate control variables used in the analysis of treatment impact and to further check for balance across treatments. Six farmers per group were randomly selected from among the farmers present during the census meeting. If fewer than six farmers were present at the census meeting, additional farmers were selected from among those listed as members but not present. In case any of the selected farmers were not available, replacements were selected from a randomly ordered list of six additional farmers, selected in the same fashion as the primary sample. A total of 892 individual farmers out of 3605 listed farmers were interviewed.[9] A group level questionnaire was administered to one or more group leaders. A follow-up survey with the same baseline respondents was conducted in March-April 2018, at the end of the season. Five of the baseline respondents could not be tracked down for follow-up, resulting in 888 observations in this round of data.

Administrative data on farmers’ Aflasafe purchases was collected during sales visits in November and early December 2017. For each farmers who purchased Aflasafe (including those who purchased less than 4 kg), name, gender, land area under maize, and the number of packets of Aflasafe purchased (with and without insurance) were recorded. This data was used to construct the main outcome variables: Aflasafe adoption (equal to 1 if the farmer purchased Aflasafe and 0 if the farmer did not), and adoption intensity (a continuous variable indicating the amount of Aflasafe purchased).

2.5 Randomization

2.5.1 Output market linkage treatment

The 152 groups in our study are located in 124 villages. To eliminate within-village spillover effects, assignment to the market linkage treatment was randomized at the village level. This randomization was stratified by county and the other experimental treatment.

Table 2 provides summary statistics across market linkage treatments. For a description of the construction of these variables, we refer to the registered Pre-Analysis Plan.[10] We note here that rainfall index insurance triggers are included as indicators for historic rainfall at the specific location.

In general, we find that the market linkage treatment groups are well-balanced on almost all observables. We do, however, find that farmers in the market linkage treatment were more likely to be present during the census meeting. Given that we test for balance on 27 variables, a significant difference on one of these is not unexpected and does not indicate structural differences across treatments. We control for farmers’ presence during the census meeting in the analysis below, as well as for other observables.

[9] In 20 groups, it was not possible to interview six farmers and only five were interviewed.
[10] https://www.socialscienceregistry.org/trials/1373

Table 2. Balance at baseline across market linkage treatments

	Market linkgage			No market linkage			Diff
	N	Mean	SD	N	Mean	SD	P
Control variables in impact regression:							
Bundled insurance	1333	0.552	0.497	1380	0.504	0.500	0.654
Individual present during the census meeting	1333	0.513	0.500	1380	0.423	0.494	0.026
Farmer sex	1333	0.244	0.430	1380	0.214	0.410	0.547
Group mean of:							
- Age of the farmer (completed years)	1333	50.2	7.8	1380	50.1	7.7	0.903
- Years of education completed by head	1333	6.95	2.07	1380	7.03	1.96	0.828
- Relationship with the head	1333	0.601	0.274	1380	0.583	0.294	0.732
- Asset index	1333	5.51	1.07	1380	5.77	1.11	0.224
- Total land under maize main season previous year (acre)	1333	1.49	0.63	1380	1.40	0.77	0.500
- Maize harvest main season previous year (kg)	1333	439	381	1380	424	394	0.838
- Maize marketing: whether sold any maize last season	1333	0.457	0.303	1380	0.489	0.344	0.622
- Total expenditures on agr. inputs & labour main season previous year (KES)	1333	10978	5342	1380	10595	5243	0.682
- Propensity for social learning dummy	1333	0.483	0.257	1380	0.476	0.286	0.898
- Aflatoxin knowledge index	1333	0.012	0.351	1380	-0.063	0.400	0.301
- Knowledge and experience with insurance	1333	1.35	0.42	1380	1.31	0.42	0.601
- Individual trust index	1333	-0.006	0.234	1380	-0.006	0.293	0.989
- Punishment index	1333	0.037	0.471	1380	-0.069	0.522	0.277
- Quantitative risk aversion score	1333	4.43	1.19	1380	4.34	1.29	0.680
County:							
- Meru	1333	0.482	0.500	1380	0.417	0.493	0.542
- Tharaka Nithi	1333	0.167	0.373	1380	0.153	0.360	0.858
- Embu	1333	0.351	0.477	1380	0.430	0.495	0.450
Group level trust index	1333	-0.006	0.234	1380	-0.006	0.293	0.989
Group punishment index	1333	0.037	0.471	1380	-0.069	0.522	0.277
Group capacity index	1333	0.115	0.534	1380	-0.074	0.448	0.121
Proportion of group members female	1333	0.773	0.250	1380	0.800	0.228	0.557
Rainfall index insurance trigger for vegetative stage	1333	35.8	12.0	1380	34.9	13.2	0.740
Rainfall index insurance trigger for flowering stage	1333	1.47	0.60	1380	1.40	0.64	0.619
Rainfall index insurance trigger for ripening stage	1333	94.2	16.1	1380	94.8	16.4	0.862

Note: P-values are corrected for clustering at the village level using the Huber and White sandwich estimator.

2.5.2 Rainfall index insurance treatments

Farmers in the optional insurance treatment had the option to buy a package of Aflasafe without insurance at 320 KSH, while those in the bundled insurance treatment could only purchase it at 400 KSH. A pilot study conducted the previous year found that information on price differences spread among nearby farmer groups and discouraged adoption among groups to which a higher price was charged. To limit such spillover effects across insurance treatments, we created eight comparable but geographically distinct clusters of farmer groups within each of the study counties (four in Meru, two in Tharaka Nithi and twoin Embu) and subsequently assigned these clusters to either the bundled or the optional insurance treatment. Subject to a minimum geographical distance of five km between clusters, we aimed to select similar farmer groups into the clusters within each county. Similarity was defined based on the Euclidean distance in the six-dimensional space formed by the standardized values of the variables summarized in Table 2.

To this end, we started with the population of 224 groups from our group census and first dropped farmer groups close to the county borders to achieve a minimum distance of groups in different counties of at least 5 km. Subsequently, we excluded any groups within linear 5 km bands dividing the remaining groups into similarly-sized clusters. From the groups on each side of the band, we iteratively selected matched pairs across each cluster with the lowest Euclidean distance into our sample. Both the position of the bands and the number of groups to be selected in each county were selected to minimize the total Euclidean distance across paired groups in the final sample. To ensure that the insurance treatments were spread out geographically, we manually decided which clusters would receive the same treatment. Finally, we randomly assigned the bundled insurance to one of the two groups of four clusters.

Table 3 provides summary statistics across insurance treatments. The first section in this table shows the variables used in our cluster construction. We find no statistically significant differences on these variables, indicating that our method succeeded in constructing geographical clusters with similar characteristics. The following sections show other variables for which we checked balance later. The absence of significant differences here indicates the absence of structural differences between geographical clusters across insurance treatments.

Table 3. Balance at baseline across insurance treatments

	Bundled insurance			Optional insurance			Diff
	N	mean	sd	N	mean	sd	p
Variables used to construct geograpical clusters:							
Group size	1432	31.1	15.1	1281	27.3	10.7	0.649
Group mean amount spent on fertilizer	1432	1821	1855	1281	2278	2061	0.733
Group proportion that used fertilizer	1432	0.613	0.399	1281	0.604	0.364	0.969
Group mean harvest normal season	1432	5.49	4.22	1281	6.21	4.32	0.821
Knowledge and experience with insurance	1432	-0.025	1.040	1281	0.061	0.962	0.749
Aflatoxin knowledge	1432	0.099	1.364	1281	-0.019	0.698	0.731
Variables checked after construction of geographical clusters:							
Group aggregated before	1432	0.244	0.430	1281	0.077	0.267	0.363
Mean proportion of bags of maize sold from a normal harvest	1432	0.422	0.236	1281	0.444	0.261	0.919
Rainfal index insurance trigger for vegetative stage	1432	36.626	11.258	1281	33.843	13.860	0.863
Rainfal index insurance trigger for flowering stage	1432	1.464	0.627	1281	1.407	0.613	0.959
Rainfal index insurance trigger for ripening stage	1432	92.016	13.866	1281	97.368	18.140	0.625
Control variables in impact regressions:							
Market linkage	1432	0.514	0.500	1281	0.466	0.499	0.471
Individual present during the census meeting	1432	0.474	0.500	1281	0.460	0.499	0.751
Farmer sex	1432	0.267	0.442	1281	0.186	0.389	0.363
Group mean of:							
- Age of the farmer (completed years)	1432	48.6	6.7	1281	51.9	8.5	0.231
- Years of education completed by head	1432	6.67	1.81	1281	7.35	2.18	0.163
- Relationship with the head	1432	0.597	0.291	1281	0.585	0.276	0.875
- Asset index	1432	5.37	1.05	1281	5.95	1.07	0.159
- Total land under maize main season previous year (acre)	1432	1.24	0.49	1281	1.68	0.83	0.169
- Maize harvest main season previous year (kg)	1432	403	387	1281	462	386	0.815
- Maize marketing: whether sold any maize last season	1432	0.482	0.330	1281	0.464	0.318	0.969
- Total expenditures on agr. inputs & labour main season previous year (KES)	1432	10937	4679	1281	10611	5904	0.861
- Propensity for social learning dummy	1432	0.518	0.262	1281	0.436	0.277	0.775
- Aflatoxin knowledge index	1432	-0.101	0.420	1281	0.059	0.305	0.405
- Knowledge and experience with insurance	1432	1.38	0.39	1281	1.27	0.45	0.745
- Individual trust index	1432	0.011	0.251	1281	-0.025	0.280	0.627
- Punishment index	1432	0.007	0.497	1281	-0.044	0.503	0.809
- Quantitative risk aversion score	1432	4.50	1.34	1281	4.26	1.12	0.251
County:							
- Meru	1432	0.477	0.500	1281	0.418	0.493	0.929
- Tharaka Nithi	1432	0.163	0.370	1281	0.155	0.362	0.977
- Embu	1432	0.360	0.480	1281	0.426	0.495	0.942
Group level trust index	1432	0.011	0.251	1281	-0.025	0.280	0.627
Group punishment index	1432	0.007	0.497	1281	-0.044	0.503	0.809
Group capacity index	1432	0.123	0.591	1281	-0.097	0.340	0.429
Proportion of group members female	1432	0.762	0.247	1281	0.815	0.227	0.411
Rainfall index insurance trigger for vegetative stage	1432	36.6	11.3	1281	33.8	13.9	0.863
Rainfall index insurance trigger for flowering stage	1432	1.46	0.63	1281	1.41	0.61	0.959
Rainfall index insurance trigger for ripening stage	1432	92.0	13.9	1281	97.4	18.1	0.625

Note: Bootstrapped p-values obtained with wild bootstrap using Rademacher weights and imposing the null hypothesis as proposed by Cameron, Gelbach and Miller (2008)

3. EMPIRICAL STRATEGY

2.1 Population and sample

As our experiment allowed new group members to buy Aflasafe, the final group composition may be endogenous to the experimental treatment. We therefore use the farmers listed during the group census as the sample for analysis.11

Since being surveyed at baseline may affect later technology adoption behavior and bias treatment effect estimates in general (Zwane et al, 2011) and in our study specifically (Treurniet, 2018), impacts for the sub-sample of non-surveyed farmers are likely to be most externally valid. We therefore focus our main analysis on farmers that were not surveyed at baseline.12 In the selection of the survey respondents, preference was given to farmers who were present during the group census meeting. Present farmers are therefore under-represented in this non-surveyed sub-sample. We correct for this under-representation by reweighting observations based on the likelihood of inclusion in the sample, given an individual's presence at the meeting.

3.1 Market linkage treatment

To assess the effect of the premium market linkage treatment on farmers' adoption of Aflasafe, we estimate the following equation both with and without controls:13

$$Adoption_{ijv} = \alpha_1 + \beta_1 \cdot Market_v + (\gamma_1 \cdot X_{ij}) + \varepsilon_{ijv1}, \qquad (1)$$

Where $Adoption_{ijv}$ represents Aflasafe adoption or adoption intensity by farmer i in farmer group j in village v, and $Market_j$ indicates whether the group was assigned to the market linkage treatment. X_{ij} is the vector of controls, as specified in the Pre-Analysis Plan and listed in Table 2. ε_{ijv1} is the error term. Standard errors are estimated using the Huber and White sandwich estimator to account for clustering at the village level.

To test the impact of our market linkage treatment, we test whether $\beta_1 = 0$.

3.2. Rainfall index insurance treatments

To assess the effect of the bundled insurance treatment on farmers' adoption of Aflasafe, we estimate the following equation both with and without controls:

$$Adoption_{ijk} = \alpha_2 + \beta_2 Bundled_j + (\gamma_2 \cdot X_{ij}) + \varepsilon_{ijk2}, \qquad (2)$$

Where $Adoption_{ij}$ represents Aflasafe adoption or adoption intensity by farmer i in farmer group j in geographical cluster k, $Bundled_j$ indicates assignment to the bundled insurance treatment, and X_{ij} is a vector of control variables, as specified in our Pre-Analysis Plan and listed in Table 3. ε_{ijk2} is the error term. Given the small number of geographical clusters in our experiment, we correct for geographical clustering using a wild bootstrap-t procedure as proposed by Cameron, Gelbach and Miller (2008).

To test the impact of bundling Aflasafe and insurance (versus offering farmers the option to buy Aflasafe either with or without insurance), we test whether $\beta_2 = 0$.

3.3 Alternative samples

We perform the same analysis on two alternative samples. First, although we randomly selected the sample to be surveyed, actual participation in the survey may be endogenous. Our primary sample, which excludes surveyed farmers, may thus be constituted of relatively less engaged members of participating farmer groups. As a robustness check, we therefore check the representativeness of our results by performing the same analysis as above on the subsample that excludes all twelve farmers who were randomly selected

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[11] For one group, the group census list was lost and re-taken later. Although the group size had not changed, this might have affected the sample composition. Excluding this one group from our analysis, however, does not affect our results.
[12] The proportion being surveyed at baseline did not significantly differ across treatments ($p = 0.627$ for comparison across market linkage treatments and $p = 0.513$ for comparison across insurance treatments).
[13] All estimates are intention-to-treat. We cannot estimate the effect of treatment on the treated, as we do not have information on which farmers were aware of the premium price.

as primary or replacement respondents, while still correcting for the under-representation of present farmers in this sample. Second, we complete the analysis using the full sample, including the five to six farmers surveyed at baseline, as specified in our Pre-Analysis Plan.[14] As being surveyed at baseline significantly affects adoption in our study, we additionally control for baseline survey status when we include baseline controls in these regressions.

4. RESULTS

In Table 4 we report estimates of the impact of being offered a premium price. We analyze whether farmers in groups assigned to the market linkage treatment were more likely to purchase any Aflasafe and whether adoption intensity, measured as the quantity of Aflasafe purchased (in KGs), was higher in these groups. Columns (1) and (2) of Table 4 show no significant impact of the market linkage treatment on the extensive margin of adoption. The point estimates suggest an increase in adoption of around four percentage points (close to one third of the control group mean), but the estimates are statistically insignificant. In contrast, the amount of Aflasafe purchased is significantly higher in groups assigned to the market linkage treatment. The estimates in columns (3) and (4) show that these farmers purchased 0.28 kg more Aflasafe on average, an increase of almost 100% relative to the control group.

Table 4. Impact of market linkage treatment

	Outcome variables			
	(1) Adoption	(2) Adoption	(3) Intensity (kg)	(4) Intensity (kg)
Market linkage	0.036	0.043	0.276***	0.278***
	(0.026)	(0.027)	(0.083)	(0.078)
Baseline controls	No	Yes	No	Yes
Villages	124	124	124	124
Observations	2713	2713	2713	2713
Mean of no market linkage	0.128	0.128	0.290	0.290

Notes: Standard errors clustered at village level in parentheses; * p<0.10, ** p<0.05, *** p<0.01

Our findings suggest that farmers who purchase Aflasafe use it first on maize produced for their own consumption. Endline descriptive statistics in Table 5 indicate that among farmers who purchased Aflasafe, 83% (in the market linkage group) to 89% (in the control group) reported having safe maize for home consumption as a reason for doing so. In contrast, the ability to sell maize at a premium was reported by only 5% of farmers in the control group, compared to 19.4% in the market linkage group. Aflatoxin knowledge increased to the same extent in groups with and without the market linkage (the knowledge index is standardized to have mean zero and standard deviation 1 at baseline), and both groups hold similar beliefs about the efficacy of Aflasafe.

Table 5. Endline descriptive statistics

	Market linkgage			No market linkage			Diff
	N	mean	sd	N	mean	sd	p
Aflatoxin knowledge index at endline	448	0.485	0.628	441	0.520	0.579	0.378
Efficacy belief:							
- No chance of aflatoxin	420	0.576	0.495	408	0.600	0.490	0.564
- Small chance of aflatoxin	420	0.276	0.448	408	0.265	0.442	0.741
- 50/50 chance of aflatoxin	420	0.138	0.345	408	0.132	0.339	0.841
Reasons for purchasing Aflasafe (self-reported):							
- To have save maize for home consumption	175	0.829	0.378	176	0.886	0.318	0.156
- To be able to sell my maize at a premium	175	0.194	0.397	176	0.051	0.221	0.000
- To have safe maize for sale	175	0.457	0.500	176	0.438	0.497	0.741
Proportion of Aflasafe bought with insurance[1]	183	0.760	0.429	146	0.733	0.444	0.826

Notes: p-values corrected for clustering at the village level using the Huber and White sandwich estimator.
[1] Sample restricted to optional insurance treatment

[14] The Pre-Analysis Plan also includes equations (1) and (2) for the sub-sample of surveyed farmers only. The strong impact of being surveyed on Aflasafe purchase leads us to conclude that these results do not accurately portray the impact of the interventions. We therefore present the full sample impact results here and leave impact results for the sub-sample of surveyed farmers for another paper (Treurniet, 2018).

While the premium price did incentivize farmers to purchase more Aflasafe, it mostly did so among farmers who decided to purchase some Aflasafe regardless of the premium. What could explain the absence of impact on the extensive margin? Apparently, the premium offered was insufficient to fully compensate farmers who have not already purchased Aflasafe for the investment. However, it still served to encourage treatment of a greater area of maize. Our interpretation is that the option of selling at a premium price allowed farmers to invest more in the safety of maize for home consumption in the face of an uncertain harvest. If the harvest was lower than expected, the treated maize would be used for home consumption, while in the case of a bumper crop, the excess could be sold at a premium.

To illustrate, using the mean values shown in Table 1, a farmer would need to apply Aflasafe to 0.51 acres planted with maize in a normal year to grow a sufficient volume of treated maize for her family's consumption. The cost of Aflasafe in this scenario is 206 KSH. But in a bad year, Aflasafe would have to be applied to 1.30 acres to attain the same volume of treated maize, at a cost of 519 KSH. Without the market incentive, a farmer might be hesitant to spend this much on Aflasafe, and risk wasting over 300 KSH in the case of a normal harvest (and even more in case of a good harvest). But with the incentive, such a farmer can safely purchase enough Aflasafe to ensure enough treated maize even in a bad year, knowing that if the 1.30 acres yields more maize than her household requires, she will reap a profit of as much as 616 KSH from treating her land, in addition to producing safer maize for her family's consumption.

Our results in Table 4 indicate that control group adopters purchased 2.27 kg of Aflasafe, on average. This is sufficient to treat 0.57 acres of land, very close to the mean value of 0.51 acres required to ensure safe maize for own consumption in a normal year. Adopters in groups receiving the market linkage treatment purchased an average of 3.32 KG, sufficient to treat 0.83 acres. Treating this area of land with Aflasafe means a family will be closer to producing enough safe maize to cover their own consumption needs even if the harvest is poor (though still short of the mean poor harvest requirement of 1.3 acres). In effect, the premium makes precautionary investment in the treatment of maize for home consumption less costly. Another potential explanation for this result is that concern about food safety for home consumption and propensity to invest in an attribute if incentivized are correlated.

Table 6 reports the impact of being offered Aflasafe bundled with rainfall index insurance (as opposed the option to buy Aflasafe either with or without rainfall index insurance). We find no evidence that forcing farmers to buy insurance together with Aflasafe affected demand for Aflasafe, either on the extensive or intensive margin. This could be because demand for insurance was high in the group for which it was optional: in the optional insurance condition, three quarters of the Aflasafe purchased was purchased with insurance (Table 5, bottom row). Maize yields in the study region are highly variable. Based on official government statistics the ratio of average maize yield in Tharaka Nithi County in the worst vs. best year between 2012-2014 was 57%. Variability for Meru and Embu Counties is slightly lower, with the minimum annual yield at 65% and 76% of the best, respectively. In addition, the small number of clusters over which this treatment was randomized limited statistical power to detect impacts of the insurance treatment.

Table 6. Impact of bundled vs. optional insurance

	Outcome variables			
	(1)	(2)	(3)	(4)
	Adoption	Adoption	Intensity (kg)	Intensity (kg)
Bundled insurance	-0.006	0.005	-0.116	-0.032
	(0.024)	(0.022)	(0.080)	(0.078)
Baseline controls	No	Yes	No	Yes
Geographical clusters	8	8	8	8
Observations	2713	2713	2713	2713
Mean of optional insurance	0.149	0.149	0.490	0.490

Notes: Standard errors clustered at geographical cluster level in parentheses. Bootstrapped p-values obtained with wild bootstrap using Rademacher weights and imposing the null hypothesis as proposed by Cameron, Gelbach and Miller (2008). * p<0.10, ** p<0.05, *** p<0.01

4.1 Robustness checks

As discussed in Section 3, our main analysis focuses on the sub-sample of non-surveyed farmers. This was driven by the concern that being surveyed at baseline might itself affect technology adoption, and thus bias treatment effects. However, being surveyed at baseline was not entirely random. While we account for the probability of selection given presence at the census meeting through re-weighting, we did not always manage to interview the first six sampled farmers. Whether or not a sampled farmer actually participated in the baseline survey could reflect unobserved characteristics correlated with the probability of adopting a new technology.

To assess the robustness of our results with respect to the estimation sample, we estimate treatment effects across two alternative samples. Table A1 in the Appendix presents results for the market linkage treatment. In columns (1) to (4) the sample excludes all farmers who were listed for the baseline survey (either in the list of the first six farmers sampled, or in the list of six additional farmers, as explained in Section 2.4), irrespective of whether or not they participated in the survey. Columns (5) to (8) present the estimates for the full sample, including all farmers surveyed at baseline. Similarly, Table A2 in the Appendix presents estimates of the bundled insurance treatment for these alternative samples. These results indicate that sample selection does not affect our findings: the market linkage premium did not significantly affect Aflasafe adoption in either sample, while the amount purchased increased significantly in all samples. The insurance treatment does not affect adoption or intensity in either alternative sample.

6. DISCUSSION

Many food safety hazards, including contamination with fungal toxins, are most effectively addressed at production. Technologies appropriate for use by small-scale producers are available, but adoption is a challenge. In settings where the scale of production is small and output markets informal, incentives to invest in costly to observe attributes such as food safety are absent. To create the market conditions for pass-through of price rewards for food safety, farmers' produce must first be aggregated to a volume at which it can be tested for hazards at reasonable cost.

Another barrier to adoption of food safety technologies is production risk. These technologies must often be applied before the outcome of a stochastic production process is realized. Their use thus increases production costs with certainty, but has an uncertain impact on the value of production. This is the case whether farm produce is consumed solely by the household or sold.

We tested the impact of two market-based innovations on the adoption of a newly available technology for control of aflatoxin, the biocontrol product Aflasafe. One innovation was to bundle Aflasafe with rainfall index insurance. This had no impact on adoption of the technology, possibly due to the high proportion of farmers who chose to adopt the index insurance when it was offered on an optional basis.

The second innovation was to offer a price premium for maize that had been treated with the Aflasafe and aggregated at the group level. The value of the premium offered for safe maize was modest – approximately 5% of the value of maize in the year it was offered. We find that the group-level premium increases the intensity of Aflasafe adoption. This shows that members of producer groups are able to overcome potential barriers to collective action, and trust that others in the group will treat any maize that is aggregated. However, we find no impact on the extensive margin of adoption: farmers that did not adopt Aflasafe without the premium are not persuaded to do so when the premium is offered. This finding contrasts with that of a recent study in which a significant increase in adoption was catalyzed by a premium for safe maize at the individual farmer level (Hoffmann and Jones, 2018). In that study, the premium was set artificially high, and offered on only the first 45 KG of maize.

Our preferred explanation for this is that farmers who anticipated the possibility of a poor harvest treated a greater area of their farm with Aflasafe to ensure themselves of an adequate supply of safe maize for household consumption. This explanation is consistent with the observation that at the end of the maize growing season, which turned out to be a bad one in which insurance payouts were triggered for 98% of farmers who had successfully activated their rainfall index insurance contract, only 20 of 76 eligible groups actually aggregated any maize through the project.

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APPENDIX

Table A1. Impact of market linkage vs. no market linkage alternative samples

	Outcome variables							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Adoption	Adoption	Intensity (kg)	Intensity (kg)	Adoption	Adoption	Intensity (kg)	Intensity (kg)
Market linkage	0.023	0.032	0.231**	0.234***	0.021	0.024	0.215**	0.198**
	(0.027)	(0.027)	(0.090)	(0.082)	(0.027)	(0.026)	(0.089)	(0.078)
Baseline controls	No	Yes	No	Yes	No	Yes	No	Yes
Sample	Non-listed	Non-listed	Non-listed	Non-listed	Full	Full	Full	Full
Villages	118	118	118	118	124	124	124	124
Observations	1795	1795	1795	1795	3605	3605	3605	3605
Mean of no market linkage	0.111	0.111	0.246	0.246	0.174	0.174	0.441	0.441

Notes: Standard errors clustered at village level in parentheses; * p<0.10, ** p<0.05, *** p<0.01

Table A2. Impact of bundled insurance vs. optional insurance alternative samples

	Outcome variables							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Adoption	Adoption	Intensity (kg)	Intensity (kg)	Adoption	Adoption	Intensity (kg)	Intensity (kg)
Bundled insurance	-0.001	0.018	-0.081	-0.010	-0.011	0.006	-0.104	0.017
	(0.026)	(0.019)	(0.088)	(0.055)	(0.022)	(0.022)	(0.070)	(0.078)
Baseline controls	No	Yes	No	Yes	No	Yes	No	Yes
Sample	Non-listed	Non-listed	Non-listed	Non-listed	Full	Full	Full	Full
Geographical clusters	8	8	8	8	8	8	8	8
Observations	1795	1795	1795	1795	3605	3605	3605	3605
Mean of optional insurance	0.123	0.123	0.408	0.408	0.190	0.190	0.601	0.601

Notes: Standard errors clustered at geograpical cluster level in parentheses. Bootstrapped p-values obtained with wild bootstrap using Rademacher weights and imposing the null hypothesis as proposed by Cameron, Gelbach and Miller (2008). * p<0.10, ** p<0.05, *** p<0.01

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