Improving food safety on the farm: Experimental evidence from Kenya on agricultural incentives and subsidies for public health

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Abstract

Evidence is emerging that foodborne illness accounts for a staggering health burden in developing countries. However, standard approaches used by developed country governments to ensure food safety are not appropriate in settings where regulatory enforcement capacity is weak and most firms are small and informal. Using a randomized field experiment, we test the impacts on farmer adoption of subsidies for technologies that improve food safety and a price premium for safer produce. We find that the food safety practices of farmers who produce maize for sale are inferior to those of farmers who produce maize only for household consumption, but that both a price incentive and technology subsidies can partially close this gap. We combine our experimental adoption results with prior evidence on the efficacy of the technologies studied to simulate the public health impacts of alternative policies. Our simulations show that interventions to reduce aflatoxin exposure are likely to be cost-effective based on averted poisoning deaths and cancer cases alone. Potential impacts on stunting, which are not as well established and more difficult to value, would imply additional health benefits. Of the policy options considered, providing training and plastic drying sheets to farmers free of charge is the most cost-effective.

JEL Codes: **I12** Health behavior; **I15** Health and economic development; **I18** Public Health; **Q12** Micro analysis of farm firms; **Q16** Agricultural technology

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1 Introduction

Foodborne illnesses account for a global burden of disease comparable to that of tuberculosis, and more than double that of maternal health disorders and deaths (WHO, 2015; GBD, 2017). Most of these illnesses are preventable and can be avoided with safe production and handling practices. As a result, the vast majority of the health burden from unsafe food is located in developing countries, where regulatory enforcement capacity is weak.

Many food safety hazards, including pathogens and fungal toxins, originate on-farm. Addressing food safety at this stage is challenging in poor countries because farm sizes are typically very small, traceability systems are limited to high-value crops destined for export, and much if not most of the food supply is traded through informal markets. Food safety systems developed in richer countries may not be feasible in such environments. Farm families, who are often the sole consumers of their produce, may lack the awareness or financial resources to invest in food safety. In such environments, public investment may be required to promote improved production practices that ensure public health. Understanding how the behaviors of farmers and others involved in food markets respond to costs and incentives for producing safe food is critical to this effort.

The focus of this study is a food safety hazard that constitutes a major public health concern in Africa. Aflatoxin is a toxin produced by the *Aspergillus* fungus that affects a number of food crops; maize and groundnuts are particularly susceptible. Acute exposure to aflatoxin through consumption of highly contaminated foods can result in aflatoxin poisoning (aflatoxicosis), which manifests as severe hepatitis with vomiting, abdominal pain, and jaundice, and is fatal in 25% of cases (Strosnider et al., 2006). Chronic exposure to aflatoxin has been shown through animal and epidemiological studies to cause hepatocellular carcinoma (HCC) (Wang et al., 1996; Henry et al., 2002; Omer et al., 2004; Strosnider et al., 2006). HCC constitutes 70-90% of all liver cancer, the sixth most prevalent cancer worldwide and the second leading cause of cancer deaths among men (Torre et al., 2015). The age-adjusted incidence of HCC is more than twice as high as in developing as in developed countries (*ibid*).[1] Aflatoxin exposure in utero and early childhood has also been associated with stunted physical growth in longitudinal studies (Gong et al., 2004; Turner et al., 2007) and a recent randomized controlled trial (Hoffmann et al., 2018a).

Aflatoxin contamination can begin in the field, but tends to increase most rapidly after harvest. Contamination is increased by post-harvest contact of crops with soil (a reservoir of the fungus), inadequate drying, and poor storage conditions. Effective technologies exist to prevent contamination but are not commonly used because aflatoxin is effectively unobservable. Aflatoxin tests exist, but these are prohibitively costly for an individual small-scale farmer or trader in Kenya, the setting of this study. Most small-scale farmers in the study region consume their own maize or sell through local informal markets, where testing for aflatoxin is non-existent. Aflatoxin safety is therefore not rewarded by higher prices.

This situation leads to a high rate of chronic aflatoxin exposure. In Kenya, where maize is the primary staple, between 15% and 65% of the grain contains aflatoxin above the regulatory limit (Lewis et al., 2005; Daniel et al., 2011; Mutiga et al., 2014, 2015; Hoffmann and Moser, 2017). The eastern part of the country is considered a global aflatoxin hot-spot and periodically experiences outbreaks of acute aflatoxin poisoning resulting in fatalities (Daniel et al., 2011). Not surprisingly, Kenyan consumers have a strong preference for own-produced rather than purchased maize (Hoffmann and Gatobu, 2014).

We hypothesize that encouraging farmers to adopt aflatoxin-prevention technologies could be an effective public health intervention. Potential approaches to encouragement could include (i) training farmers on the use of existing prevention technologies, (ii) subsidizing the cost of existing technologies, (iii) making new technologies available, potentially at subsidized costs, and (iv) increasing observability of aflatoxin in local markets, thereby generating a price premium for aflatoxin-safe maize and increasing the market return to investing in aflatoxin prevention. In order to estimate the potential return in terms of public health of any of these strategies, we first require evidence

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[1] This is due to both higher levels of aflatoxin exposure, and higher rates of infection with hepatitis B virus, which amplifies the carcinogenic effect of aflatoxin.

on the expected response of farmers to technology promotion under different combinations of cost subsidies and price premiums. In order to generate this evidence, we conducted a randomized field experiment to test the impact of various strategies for the promotion of aflatoxin-prevention technologies in Eastern Kenya.

Our study examines farmers' responses to training on aflatoxin prevention coupled with free provision of a simple, low-cost, widely available technology: plastic sheeting for use as a barrier between maize and the soil while sun-drying. We additionally observe adoption of a new, higher-cost, more advanced technology: a mobile, flatbed dryer for ensuring maize grain is fully dry before storage, promoted under three different cost schemes. For both of these technologies, we report adoption both with and without a simulated price premium for selling aflatoxin-safe maize after three months of storage.

Findings from the trial indicate that Kenyan farmers producing maize for the market are less likely to adopt aflatoxin-prevention technologies relative to farmers producing for home consumption. Given the increasing share of food transacted through markets as a result of rapid urbanization, this has significant implications for public health. We additionally find that subsidies greatly increase adoption of technologies by both subsistence and market producers, and that incentives close the adoption gap between these two types of farmers.

We calculate the private and public costs of these technologies under the various combinations of subsidy and incentive; we also combine original consumption data and published research findings to simulate the reduction in aflatoxin-related diseases associated with the levels of technology adoption observed under each of these scenarios. We compare the cost per disability-adjusted life year saved for these technology promotion schemes to benchmark costs within the public health literature. We find that all of the technology promotion schemes studied here would be considered cost effective as public health interventions, with some costing far below the international benchmark. Finally, we discuss the implications of these findings for policies regarding consumer welfare and health inequality.

2 Study design

2.1 Aflatoxin prevention

There are a number of low-cost actions that farmers can take post-harvest to reduce the probability of aflatoxin contamination. Adequately drying harvested maize before storing it is the front-line defense against fungal growth and thus aflatoxin. Maize may be exposed to molds during cultivation and harvest, but these will only continue to multiply and produce aflatoxin if stored maize contains adequate moisture. A moisture content of 13.5% or below is recommended for long-term storage of maize. Farmers in Kenya typically dry their maize in two steps. First, they lay the cobs on the bare ground for a few days to be sun-dried. The kernels are then removed from the cobs (shelled). Some farmers further dry the maize after shelling, typically by laying it back on the bare ground or on a sheet made of used woven storage bags. The final moisture content achieved through this process depends on the weather. Rains and high relative humidity during the post-harvest period are common in the study area, so sun-drying alone is often not sufficient to attain the recommended moisture content.

During drying, exposure to the Aspergillus fungus can be reduced by ensuring that maize does not come into contact with soil, as the fungus lives in the soil and often infects the crop during this post-harvest stage. The use of an impermeable barrier between maize and the ground while drying is thus an effective strategy for aflatoxin control. Use of a barrier also prevents transmission of humidity from the soil, and facilitates collection of grain at night and in case of rain. While the majority of farmers in the study area dry their shelled maize on some kind of barrier, the woven plastic bags that are often used are permeable and difficult to clean. Fungal spores present in the soil or remaining on these bags from the previous storage season may reach the drying crop. Impermeable plastic sheeting is available in the study area, but is rarely used for drying maize.

Sorting out damaged or rotten maize before storage also reduces aflatoxin contamination by preventing fungi from infected grains from spreading. Depending on the quality of sorting, this can be labor intensive and can result in significant reduction of volume. Treating the maize with chemical insecticides before storage can also reduce aflatoxin, as insects can spread fungal spores and damage grains, making it more vulnerable to fungal infection (Noomhorm and Cardona, 1991). However, chemical treatment is widely seen in the study area as undesirable.[2] Further, the main storage pesticide used on maize in Kenya, Actellic Super Dust(One Acre Fund, 2015), has been shown to have no impact on production of aflatoxin (El-Kady et al., 1993). it also contains permethrin, which has been banned in Europe since 2013 (EU, 2019) and is classified by the US EPA as a likely carcinogen (Toynton et al., 2009).

2.2 Recruitment and baseline

The study sample consists of maize farmers in 30 randomly selected maize-growing villages in Meru and Tharaka-Nithi counties in Eastern Kenya. Each of the 30 study villages was visited in June 2013 for baseline data collection. Ahead of the baseline survey, scouts identified households with children under two years of age, or those containing a woman in her third trimester of pregnancy, using information from the village chief and snowballing.[3] In each village, an average of 23 such households were randomly selected from among those identified and were administered the baseline survey.[4]

Fifteen of the study villages were then randomly assigned to a technology treatment group. Maize farming households in these villages received access to a package of post-harvest technologies described below, and training on aflatoxin prevention. Farmers in the remaining 15 villages constituted the control group. The baseline sample includes 679 farmers.

Status as a market producer is relevant to practices that determine unobservable quality, as farmers

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[2] For a separate study conducted by one of the authors, 100 maize consumers were interviewed at 10 small-scale mills in eastern Kenya. Of the 91 consumers who expressed a preference for maize of a particular origin (home grown or purchased), 26% cited the absence of chemical preservatives as one of up to three reasons for this preference (unpublished data, available upon request).

[3] This sampling strategy allowed for the use of common control villages by this study and a separate RCT focused on child growth.

[4] For ethical reasons, basic information on aflatoxin prevention was provided in all study villages through a training of trainers approach, considered the standard of care for aflatoxin prevention in the study region. One farmer from each of the study villages was selected in consultation with community leaders to be trained on the causes and consequences of aflatoxin contamination in maize, and on recommended practices for its prevention. The trained farmers were given printed training materials and asked to share this information with others in their communities.

who sell a portion of their maize do not capture the full benefit of the quality investment. 43% of farmers had sold any maize in the 12 months preceding the baseline survey. The primary determinant of producing maize for the market is the amount of maize harvested. The median subsistence farmer produced 150 kg in the harvest immediately preceding the baseline survey; the median market producer harvested nearly four times that (585 kg).[5] The harvest distribution for each group is shown in Figure 1.

Beyond maize harvest sizes and consumption patterns, these groups differ on a number of dimensions. Table 1 displays the means of key demographic and economic characteristics for market and subsistence producers, and p-values for tests of equality of means. Market producers are more educated, have more assets, and higher values of food consumption. Non-food expenditures of market producers are nearly a third greater than those of subsistence households, and the area of land owned is 56% higher.

Below, we examine how status as a market producer impacts a farmer's probability of adopting technologies that improve food safety, and his or her response to market incentives. We include specifications controlling for the variables shown in Table 1 to evaluate whether differences in terms of market orientation are driven by other underlying characteristics.

2.3 Intervention

The randomized intervention was designed to increase farmers' knowledge about aflatoxin control and their access to post-harvest technologies that reduce aflatoxin contamination in maize. The intervention included information on routes of aflatoxin contamination and training on good post-harvest practices for prevention, such as sufficient drying, sorting, and safe storage. It also included free provision of plastic sheeting to be used as a barrier during sun drying, and access to a newly developed mobile maize dryer, which circulated heated air around the shelled maize until

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[5] The use of "subsistence farmer" refers only to maize production and does not preclude the selling of other crops. Despite their lower production of maize, subsistence farmers consume significantly more maize from own production. This reflects the greater reliance on maize among low-income households in Kenya (Muyanga et al., 2006).

the desired moisture content was reached. Access to the dryer was provided at three different price points. The study design and sample sizes for each treatment arm are shown in Figure 2.

2.3.1 Training on aflatoxin prevention and assignment of technology subsidies

The intervention proceeded as follows: in technology treatment villages, members of each participating household were visited at their homes and invited to attend a meeting in the village, at which information was to be presented about aflatoxin prevention and the maize dryer. Participants were informed upon invitation that at this meeting, they would be able to enter a lottery through which they could win a partial discount on use of the dryer, or even free use, and that plastic sheeting on which to dry maize would be given free to all invited attendees.[6]

During the village meetings, the mobile maize dryer was described and photographs of the dryer were shown. Meeting attendees who had previously stated that they expected to harvest at least 45 kg of maize (77% of attendees) were invited to participate in a public lottery, through which the price they would be charged for use of the dryer was determined.[7] There were three possible prices: a full "commercial" price of 350 Kenyan shillings (KSh) per 90 kg bag, which covered both operating expenses and the capital cost of the dryer; a partially subsidized "NGO" price of 150 KSh per bag, reflecting the price required to cover only the operating expenses of the dryer; and a full subsidy (zero price) offer, reflecting a public service provision model in which the government or a non-profit entity would provide the drying service free of charge. Farmers were given vouchers indicating the price they had drawn.[8] This design allows us to observe the proportion of farmers

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[6] In order to achieve sufficient statistical power for the study, significant effort was made to encourage study participants to attend the meetings to which they were assigned. Fliers containing information about the meeting's purpose and the scheduled time and location were left with all invitees. Up to three attempts were made to find each invited household, and meeting information fliers as above were left with village officials to pass on to those who were not found by the third attempt. Phone calls to all invitees were made the day prior to each meeting, reminding them of the time and location.

[7] Information on participants' anticipated quantity of harvest was collected prior to the village meeting, either during the invitation visit (if the team was able to speak with the participant at this time) or as participants were gathering for the meeting (if the participant had not been interviewed during the invitation visit). Farmers with harvests lower than 45kg were not eligible to use the dryer due to the minimum operating requirement. At baseline, fewer than 15% of the sample had harvested less than 45kg in the main growing season.

[8] Hermetic storage bags were offered at the full market price of 220 KSh each to those using the dryer under the full price treatment and discounted by roughly the same proportion as the dryer for those using the dryer in the partial

willing to use the mobile drying service at three potential price points.

2.3.2 Market incentive

The second key aspect of the design is the random assignment of a market incentive for aflatoxin-safe maize. Within each village where the package of post-harvest practices was offered, 50% of farmers were assigned to the market incentive sub-treatment. These farmers were told that two to three months after harvest, they would have an opportunity to sell up to 45 kg of maize at the prevailing market price plus 15 KSh per kg (a price premium of approximately 50%), but only if the maize tested below the regulatory standard for aflatoxin contamination.[9] The timing of premium purchases was set long enough after harvest that well-dried maize would be significantly less contaminated than poorly dried maize, but also early enough that most farmers were expected to still have some maize in store.[10]

In order to minimize both confusion and potential experimental effects arising from interpersonal comparisons, separate meetings were held in each village for those assigned to the market incentive treatment versus those not offered the incentive payment.[11] The meetings were identical in content except for the explanation of the market incentive. Information on whether participants intended to use the dryer, the approximate date at which they anticipated harvesting, and the quantity of maize they expected to dry were elicited immediately after the lottery for subsidies.[12]

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subsidy group. Those in the free group were given a free hermetic bag for the first 90 kg dried, and one more for every two bags dried thereafter. Due to complications with implementation, we do not study take-up of the bags here. We note that the offer of discounted bags may have acted to increase take-up of the dryer. Implications of this feature of the design are discussed in sections 3.3 and 5.1.

[9] Sales were capped at 45 kg due to logistical and budget constraints. The premium of 15 KSh/kg was set to achieve a total premium payment that would be comparable to a realistic per-kg premium at larger volume of sale.

[10] Prices in the study region do not follow a predictable seasonal pattern. Based on data from Esoko (esoko.com), in 2015, the price was essentially flat at 25 to 26 KSh/kg between the main maize harvest in February and the minor one in August. While other years exhibit more variation (in 2016 the price per kg rose from 22 KSh in April to 26 KSh in July and in 2017 it rose from 33 in March to 39 in June), the structure of the incentive ensured that it remained relevant, regardless of farmers' expectations about prices.

[11] Attendance of participants' assigned meeting was enforced through the provision of material benefits (plastic sheeting) only to those who attended the meeting to which they had been invited. Participants were informed of this policy at the time of invitation and during calls reminding them of the meeting time.

[12] At the end of the meeting, attendees were given a booklet describing recommended post-harvest practices for aflatoxin control, information on how to access the dryer, and a reminder of the market incentive if relevant. This booklet was written in Kiswahili and made extensive use of simple graphics.

2.3.3 Mobile drying service

The drying service was offered immediately after harvest. The drying service included transportation of farmers and their maize from their homestead to the dryer location, measurement of initial grain moisture content, use of the flatbed dryer, and post-drying moisture testing. In this way, the effort cost of dryer use, which included scheduling and keeping the drying appointment, and accompanying maize to the dryer, was held relatively constant across farmers. Several measures were taken to prevent participants from using the drying service for less than their randomly assigned price. First, farmers were allowed to dry only as much maize as they had previously reported they expected to harvest. Second, farmers were asked to show the voucher indicating the price at which they were entitled to use the dryer. Finally, farmers were asked to verify their identity, either by showing their national ID or placing a call to a member of the research team using a phone number associated with the household in the study data. Participants whose maize tested at or below 13.5% moisture prior to drying were refunded the fee, and drying was not performed on their maize.[13]

2.3.4 Balance across treatment groups

We test for differences by treatment assignment groups in terms of maize production, sales, and consumption; post-harvest practices; and demographic characteristics discussed in sections 2.1 and 2.2 (see Appendix Table B1). We additionally test for balance across the various assignments within the treatment group (incentive vs. none, and level of subsidy). Of the 39 balance tests conducted, only two find differences significant at the 5% level, as expected. One of these is significant at the 1% level: those assigned the full discount had higher baseline non-food expenditures (1528 KSh/ae/mo vs. 1147 and 1297 for partial and no discount groups, respectively).

2.4 Analysis samples

We employ two distinct sub-samples for our primary analyses of technology adoption.

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[13] Due to the study year being a relatively dry year, most of the maize brought to the dryer was found to have already attained the recommended moisture level of 13.5%. Thus, only 28% of those who brought maize for drying actually had their maize dried.

To analyze plastic barrier usage, we employ all farmers who were followed up with an endline survey approximately three months after the intervention for whom we have information about drying practices. This includes 468 farmers, as shown in Table 2. For analysis of study attrition, see Appendix A.

For the analysis of mobile dryer adoption, we include all farmers who participated in the lottery for dryer discounts. As detailed in Table 2, we lose one-third of the treated sample due to non-participation in the lottery, mostly due to having an expected harvest near or below the 45 kg minimum operating requirement of the dryer.[14] An additional 55 farmers who participated in the lottery indicated at the time dryer visits were scheduled that they had less than 45 kg of maize. These farmers, 85% of whom had harvested less than expected and 51% of whom were market producers, are included in the main analysis sample.

3 Results

3.1 Baseline post-harvest practices

At baseline, prior to any intervention, we measured maize farmers' post-harvest investments in maize quality, as presented in Table 1. Of farmers who sun-dried their most recent harvest, 57% used a barrier at every stage of sun-drying. However, only 4% of farmers who sun-dried reported using an impermeable barrier. As discussed above, impermeable plastic sheets represent a significant improvement over traditional materials for preventing infection with aflatoxin-producing fungi from the soil while drying. Further, only 37% of farmers sorted out bad kernels before storing. Finally, 61% of farmers reported treating maize with storage chemicals, a practice that can reduce fungal contamination but may pose other health risks.[15] Only eight farmers (1.2%)

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[14] Only two of the farmers who refused to draw the lottery expected a maize harvest of over 90 KG; at levels of production below this, farmers likely planned to consume the little maize they harvested fresh.

[15] Farmers were not asked which chemicals they used to treat their maize. However, of 16 farmers for whom the 'other' response option was (incorrectly) selected rather than chemical dust or ash, all had used either Actellic Super Dust or Skana Super. Both of these products contain permethrin, which is banned in the EU and classified by the US EPA as a likely carcinogen. Further, Actellic has been shown to have no benefit in terms of reducing Aflatoxin (El-Kady et al., 1993).

reported undertaking all three of the recommended best practices for preventing aflatoxin (drying after shelling, using a plastic barrier while drying, and sorting before storing).

Market producers were more likely than subsistence farmers to report post-harvest practices that may have negative implications for public health. While they reported similar rates of sorting, they were significantly less likely to use a barrier at every stage of ground drying, and more likely to use storage chemicals.[16] The primary purpose of these chemicals, and the only one cited in marketing claims, is to prevent physical insect losses in stored maize; aflatoxin prevention is an additional benefit of *some* chemicals, of which some farmers may not be aware.

3.2 Adoption of post-harvest technologies for food safety

All study farmers in treatment villages were offered training on aflatoxin prevention and a plastic barrier for free. 93% of invited farmers attended a training session, and 98.5% of these received a plastic barrier as well.

3.2.1 Plastic barrier adoption

We first examine changes in plastic barrier use as a result of the free provision of plastic sheeting. Figure 3 shows reports of plastic barrier use while drying at baseline in 2013 and at endline in 2015 separately for treatment and control groups, by subsistence and market producers. Plastic use was extremely low at baseline and remained so among farmers in the control group. Among those assigned to treatment, usage increased from 3-5% to 45-55%. The increase was slightly higher for market producers, though we cannot statistically reject that the increases are the same.

We examine changes in plastic use in a regression framework. Among the 468 farmers that har-

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[16] We did not pre-specify the analysis of subsistence versus market producers. Indeed, none of the analysis was pre-specified, as the study was initiated in 2012, before registration of pre-analysis plans was standard practice in the literature.

vested and sun-dried maize in the season of interest, we estimate

$$B_i = \alpha + \delta_1 Free_i + \delta_2 Free_i \times Incentive_i + \delta_3 MP_i + \delta_4 Free_i \times MP_i \\ + \delta_5 \times Free_i \times Incentive \times MP_i + \varepsilon_i \quad (1)$$

where B_i indicates whether farmer i used a plastic barrier at all while sun-drying maize during the season immediately prior to the endline survey, $Free_i$ indicates assignment to the treatment group and thus the opportunity to receive free plastic sheeting , $Incentive_i$ indicates sub-assignment to the sales incentive group, MP_i indicates market producer status, and ε_i is a normally distributed error term.[17] Standard errors are bootstrapped to correct for clustering at the village level for all estimations.

Table 3 presents estimations of equation 1, beginning with a specification that includes only the primary (free provision) treatment variable in column 1. Additional terms are introduced in subsequent columns until all are included in column 4. For specifications including the market producer indicator (columns 3 and 4), we control for the baseline variables presented in Table 1. We see that plastic barrier usage among farmers in the control group was similar to what it was at baseline (3-4%). However, among those assigned to receive plastic sheeting, usage increased to 46% (column 1). Assignment to the incentive treatment did not significantly affect use of plastic sheeting among those that received it (column 2). Neither the effect of free provision nor of the incentive is significantly different between market and subsistence producers (columns 3 and 4). The effect of each of the two policies tested (free provision of plastic sheets alone, and the marginal effect of adding sales incentives) on market producers, and the effect of being a market producer under each policy, are shown below the regression results in col 4 of Table 3. The fact that many farmers who received the plastic sheets did not use them to dry maize suggests that other uses were likely found for this versatile material.

Of the baseline variables differentially correlated with attrition from the analysis sample across

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[17] Note that $Incentive_i$ alone is not included as the incentive was offered only to a sub-set of the group to which free plastic sheeting was provided.

treatment groups, only use of a plastic barrier at baseline is significantly correlated (positively) with plastic barrier use at endline. We estimate the magnitude of potential bias arising from this difference and conclude that it is too small to alter our finding that the incentive treatment has no impact on barrier use.[18]

3.2.2 Dryer adoption

A simple examination of take-up rates for the drying service among eligible producers reveals some interesting patterns, shown in Figure 4.[19] When the mobile drying service is offered free of charge, take-up is comparable between eligible subsistence producers at 97%, versus 89% of those who produce for the market. Yet when offered at the maximum anticipated price of 350 KSh per bag, take-up by commercial farmers falls dramatically to just 15%, while 60% of subsistence farmers still bring maize for drying. This is striking given the fact that the socioeconomic status, and in particular the consumption level, of market producers is higher, which would suggest a greater ability to pay for this technology.

Among eligible market producers, the sales price incentive increases take-up by 26 pp (46%), bringing it almost to the level of subsistence farmers. Among eligible subsistence farmers the sales price incentive has little discernible impact (3 pp), as expected since these farmers do not sell their maize.

We additionally examine these differences in a regression framework. Since farmers' statements about the amount of maize held could respond to the subsidy value drawn, we use the larger sample of 236 farmers who participated in the lottery as our sample for analysis of dryer take-up. Take-up patterns among this group are similar to those in the sub-sample who are eligible for dryer use, though rates of use are of course lower. For the sample of farmers who participated in the lottery,

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[18] Multiplying the proportion of farmers who reported using a plastic barrier at baseline (3.4 percent) by the estimated coefficient indicating treatment-specific correlation with attrition as reported in Table A2 (-0.528) and the partial correlation coefficient of plastic barrier use at baseline and follow-up (0.216) yields a point estimate for the potential upward bias in the estimated effect of just 0.4 percentage points. This is small relative to the standard error of the estimated effect of the incentive treatment.

[19] See Table 2 and its associated text for sample size and explanation of eligibility.

we estimate

$$Y_i = \alpha + \beta_1 MP_i + \beta_2 FullDisc_i + \beta_3 FullDisc_i \times MP_i + \beta_4 PartialDisc_i + \beta_5 PartialDisc_i \times MP_i + \beta_6 Incentive_i + \beta_7 Incentive_i \times MP_i + \varepsilon_i \quad (2)$$

where Y_i indicates that farmer i brought maize to the dryer for drying, $FullDisc_i$, $PartialDisc_i$, and $Incentive_i$ indicate assignment to each of the three treatments, and MP_i and ε_i are as described above. Estimations of equation 2 with and without baseline controls are presented in columns 1 and 2 of Table 4 respectively. As before, standard errors are bootstrapped to correct for potential correlation at the village level.

Estimations for the smaller sample of eligible farmers are shown in Appendix Table A2. As initially indicated by Figure 4, market producers are significantly less likely to invest in this drying technology. Without any subsidy, the difference is 32-40 percentage points (pp) (Table 4, row a). Fully subsidizing the technology increases adoption, by 37 pp for subsistence producers (row b) and by 50 pp for market producers (row k). This partially closes the gap between the producer types, reducing it from 32 to 19 pp, but a statistically significant gap remains (row n). The partial subsidy is also effective, increasing adoption by 25-26 pp for subsistence farmers (row d) and 38-39 pp for market producers (rows d+e).

While the price incentive has no impact on the behavior of subsistence maize producers (row h), it does appear to increase investment by market producers, increasing adoption of the mobile dryer by 15 to 16 pp (row m). In the presence of the incentive, the difference in adoption between market and subsistence producers is reduced to a similar magnitude as in the presence of a full subsidy, and is no longer significant (row o). Controlling for underlying socioeconomic differences between producer types does not meaningfully change the results (col 2 vs. col 1). We do not observe a significant correlation between dryer use and any of the variables differentially associated with missing dryer use data across treatments, leading us to conclude that such differences are unlikely to affect the estimated treatment effects.

3.2.3 Other post-harvest practices

We next examine the impact of the randomized training intervention on other post-harvest practices. Figures 5 and 6 show the same information as Figure 3, but for the post-harvest practices of drying shelled maize and sorting maize before storing it, respectively. Training had a large impact on drying practices: while 55% of farmers in control villages reported drying their maize after shelling and prior to storage, 76% of farmers in treatment villages reported doing so. The rate of drying was 12 pp higher and statistically significant at p=0.025 even among those in treatment villages who reported not drying their maize on plastic sheeting. We see that sorting actually fell slightly across all groups, though we cannot reject that sorting is the same across all groups at all points in time. These results indicate that training improved practices beyond the use of the technologies made available through the intervention. Results reported by Pretari et al. (2019) also suggest that training reduced aflatoxin contamination independent of the use of any technology.

Figure 7 examines the application of chemical dusts to maize before storage. We note that use of chemicals was much higher among market producers than subsistence farmers at baseline (though not for the purpose of aflatoxin control). Both treatment and control market producers reduced chemical use substantially at endline, though the decrease is significant only for market producers in the treatment group. Subsistence producers also reduced chemical use, slightly more in the treatment than control group, but the differences are not statistically significant. The observed reductions in chemical use and sorting may reflect a substitution effect between these practices and improved drying.

3.3 Discussion of adoption results

The first takeaway from these results is that in this part of Kenya, post-harvest practices relevant to aflatoxin management among smallholders are poor in the absence of any intervention. More than one-third of farmers fail to consistently use a barrier to prevent maize from contact with the soil during drying, and nearly no one uses an impermeable barrier. Fewer than 40% of farmers sort their grain before storage, and over 60% use potentially harmful storage chemicals.

Second, we see that some practices are significantly worse among market producers. This is not surprising given the unobservability of aflatoxin in local markets and the resulting lack of a price premium for aflatoxin-safe maize. Recent work in Senegal shows that market standards can be powerful motivators for adoption of technologies that improve quality of farm produce (Bernard et al., 2017). Improving the observability of aflatoxin in local markets could lead to a price premium at farm gate for safer maize. We find that, for the mobile dryer, a relatively costly technology, the existence of a price premium significantly increases the likelihood that market producers invest in aflatoxin-prevention, by nearly 50%. Due to a poor harvest in the year of the experiment, only 36% of market producers had home-produced maize in store by the time the premium price was offered.[20] If the premium had been offered on more flexible terms, we suspect that its impact could have been even stronger.

Third, we find that all farmers significantly increase their use of aflatoxin prevention technologies when these technologies are subsidized. A full subsidy increases plastic barrier use from 3% to 47%. Using a free plastic barrier to dry maize takes no more effort than using an alternative barrier, and is labor-saving relative to drying directly on the ground as it facilitates gathering maize in the event of rain or at the end of the day. This likely explains the fact that market producers are no less likely than subsistence producers to make use of the plastic sheets provided. Full subsidization more than doubles dryer adoption, and a partial subsidy of the dryer has an impact nearly equal to that of full subsidization, yielding take-up rates of 56% by subsistence farmers and 35% by market producers. However, market producers remain less likely to use the drying service even when it is fully subsidized, possibly due to the effort cost of transporting maize to the dryer.

For subsistence farmers, investing in aflatoxin prevention is purely for the benefit of their own health and that of their family. Farmers who sell a portion of their maize may also be motivated by health concerns to invest in the safety of the maize they retain for household consumption. The

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[20] This proportion was even lower among subsistence farmers, at 25%.

strong negative response of take-up to price is consistent with many other studies examining take-up of preventive health technologies for household use (Hoffmann et al., 2009; Ashraf et al., 2010; Cohen and Dupas, 2010).

In the following two sections we examine the implications of our experimental findings for policy. We first describe the costs at scale of the subsidies offered through the experiment, and the likely impact of a price premium that could be supported by the market. Then, in section 5 we simulate the potential impacts on human health of various combinations of these two approaches to promotion of on-farm aflatoxin management. For each scenario, we calculate cost-effectiveness in terms of averted illness and deaths due to cancer and aflatoxicosis, and compare this to standard cost-effectiveness benchmarks for public health interventions.

4 Costs and feasibility of interventions at scale

We have shown above that both cost subsidies and sales price incentives are effective for increasing the adoption of aflatoxin-prevention technologies. But are these approaches well-suited for implementation at the population level? We consider the cost and feasibility of scaling-up the mobile drying technology and provision of plastic sheets, as well as the feasibility of a price premium. The details of our calculations for this section are discussed in Appendix C and presented in Appendix Table C1. The cost of providing fully subsidized plastic sheeting to dry all maize produced in the Eastern region of Kenya is estimated at US$2,519,359, or $0.007 per kg of maize dried.

We estimate a cost of 2.93 KSh per kg to fully subsidize the mobile dryer, and 0.73 per kg for a partial subsidy covering the capital cost. While the full subsidy increases dryer adoption significantly, it also represents a very large public cost relative to other options. Given that a partial dryer subsidy increases dryer adoption nearly as much, it seems unlikely that full subsidization is the best policy choice. We return to this in greater detail in section 5.

We also consider the impact of developing markets to support a price premium for aflatoxin safety. A *de facto* premium for aflatoxin safety already exists in the Kenyan branded maize flour market.

Yet this requires transporting maize to the Nairobi market, where millers that do test for aflatoxin are located, which prohibitively costly due to the long distance and cess fees charged at the several county borders crossed along the way. However, local millers could be encouraged to invest in aflatoxin testing through a combination of capacity building and increased regulatory enforcement.

Based on the price premium currently offered by millers that test for aflatoxin, we estimate that a realistic wholesale premium that could be passed on to farmers for aflatoxin-safe maize would be about 2 KSh/kg.[21] This is below the full estimated cost of the maize drying service, which we estimate to be 2.35 KSh/kg. A market premium is thus unlikely to catalyze adoption of the maize dryer absent any subsidy for this technology. Under a partial dryer subsidy, only farmers with the largest harvests would be motivated by this premium. However, these farmers would account for more than 40% of marketed maize in our sample.[22]

5 Simulating impacts on health

How would scaling up the interventions tested in this paper affect human health? The links between aflatoxin and health are well-documented, in particular its contribution to liver cancer in developing countries. In this section, we simulate the impacts of alternative policies to promote drying sheets and mobile dryers on health outcomes and asses their cost-effectiveness.

We consider six policy scenarios involving three levels of subsidization (Table 5). In the first two scenarios (A and B) training and plastic sheets are provided free of charge. The maize dryer is not available. In scenarios C and D, the subsidy additionally covers the capital costs of making mobile maize dryers widely available; users pay a per-kg fee that covers the variable cost of dryer operation and maintenance. Scenarios F and G include full subsidization of training, plastic sheets, and the

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[21] The price paid by one miller per 90 kg bag of maize was 500 KSh higher than the price observed at a nearby informal market on the same day.

[22] We estimate that the farmer's cost of drying under the partial dryer subsidy would be 1.7 KSh/kg. In order for a 2KSh/kg premium to yield a return of 600 KSh (as was offered in the experiment net of the partially subsidized cost of drying), a farmer would need to dry and sell at least 2,000 kg. This is a very large quantity, and only 3.7% of the farmers in our sample had sold at least this amount in the 12 months preceding the baseline survey. However, while a realistic price premium would induce adoption for only a small share of farmers, it could have a significant impact on aflatoxin contamination in markets. That 3.7% of farmers accounted for 42.4% of all maize sold in our sample.

drying service. At each level of subsidy, we present a simulation with and without the assumption of a market premium for aflatoxin-safe maize.

For each scenario we consider five key questions: What is the efficacy of the technology based on published evidence? What is the expected level of technology adoption based on findings presented above? What are the resulting changes in dietary exposure to aflatoxin based on efficacy and adoption? What are the health implications of these dietary changes? and What isthe cost-effectiveness of each approach? Appendix D details the calculations and assumptions behind the simulation results presented in Table 5. Row numbers in the following discussion reference this table.

How much does the technology reduce contamination in maize? Based on the results of Kaaya and Kyamuhangire (2010) and Pretari et al. (2019), we estimate that training alone reduces contamination by 41%, use of plastic sheeting by an additional 29%, and use of the mechanized dryer by an additional 6% beyond the plastic (rows 1-3).

What is the expected level of technology adoption? We predict that under free provision of plastic sheeting with training (columns A & B), 44% of maize would be dried on a plastic barrier. Under partial subsidization of drying services (columns C & D), 38% of subsistence maize would be sun-dried on plastic and finished in the dryer, 6% would be sun-dried on plastic (only), and 17% would benefit from farmer training but neither of the promoted technologies. Full subsidy of the dryer (columns E & F) improves this further, with 59% dried in the dryer, 10% on plastic only, and <2% benefiting from training only.

For marketed maize, use of plastic sheets for sun-drying is similar, but the dryer is used only in the presence of the market premium. While the existence of a market price premium yields only a slight improvement in plastic use, shifting 3.5% of marketed maize from the "training only" (row 11, column A) to the "dried on plastic" category (row 12, column B), it has a strong impact on dryer take-up, increasing the share of marketed maize dried this way from zero to 25% under a partial dryer subsidy, and to 58% under a full dryer subsidy (columns D vs. C and F vs. E, row 19). In the absence of a market premium, farmers do not use the dryer on their marketed maize, even under full subsidization, due to the effort and time costs (columns C and E).

What are the expected changes in dietary aflatoxin exposure? We estimate status quo aflatoxin exposure in this region through stored maize and purchased maize separately (rows 23 and 24). To this we apply the intervention-induced reductions in dietary aflatoxin exposure from maize (rows 21 and 22), as estimated based on the simulated levels of technology adoption and efficacy of the technologies. As expected, increasing the intensity of the intervention (via premium or subsidy) increases its effectiveness in terms of the percentage reduction in dietary aflatoxin exposure from maize. This ranges from 52% in the case of provision of training and plastic sheets alone, to 67% when free access to the mobile dryer is included (row 26).

What is the relationship between dietary aflatoxin exposure and health outcomes? Consumption of highly contaminated food can cause acute aflatoxicosis. There is no reliable treatment for this condition, which can be fatal (Strosnider et al., 2006). Close to 300 deaths from aflatoxicosis were recorded in Eastern Kenya from 2001-2014, a rate of 20.8 deaths per year (see Appendix Table D2). Assuming that the number of fatalities is proportional to exposure through maize, the reductions in exposure considered here could prevent an average of between 10.7 and 14 deaths from aflatoxicosis annually in this region (row 27).[23]

While chronic dietary exposure to lower levels of aflatoxin is associated with a number of negative health impacts, the best-established of these is hepatocellular carcinoma (HCC), the most common type of liver cancer. We estimate that dietary aflatoxin exposure through maize causes 66.7 HCC cases in the region each year. Based on the estimated reductions in exposure, we find that between 34 and 45 of these cases could be prevented annually through aflatoxin mitigation (row 28).

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[23] All aflatoxicosis outbreaks have been linked to consumption of contaminated maize; aside from sorghum (to which the technologies discussed here would also apply) other foods consumed in the region that are prone to aflatoxin contamination are either consumed in quantities too small to result in aflatoxicosis (groundnuts) and or do not reach levels of contamination high enough to result in acute illness (milk).

A more speculative analysis can be conducted based on emerging evidence that aflatoxin contributes to stunting in young children. A recent cluster-randomized controlled trial conducted in the same area as the present research finds that reducing aflatoxin exposure by 44% (based on administrative data and estimates of exposure through various sources) led to a standardized mean difference (SMD) in length for age Z-score (LAZ) of 0.136 at 13 to 14 months of age (Hoffmann et al., 2018a).[24] We adjust the impact on child growth based on the estimated reduction in total dietary exposure achieved in each scenario modeled in Table 5. We find that promotion of post-harvest technologies could yield a standardized mean difference (SMD) in child linear growth of between 0.16 and 0.21 (row 29).

How does cost-effectiveness compare to other interventions? The public costs of subsidizing training, plastic sheeting, and drying technology, as discussed in section 4, are shown in USD in rows 30, 31, and 32, respectively.[25] We do not include an additional public cost for the market premium, but rather assume that the price premium is paid by consumers who choose to purchase safer brands. The increase in public cost when premiums are assumed arises from the higher level of adoption of the subsidized technology. We use these costs, and the health benefits calculated in rows 27 and 28 to estimate costs per life saved, and per disability-adjusted life year (DALY) saved, under each scenario. We also estimate the cost per child for improving growth, and the cost per SMD of LAZ, to enable comparisons with other interventions targeting child growth.

We first consider the cost per life saved by preventing deaths from aflatoxicosis and HCC (row 34). This ranges from $72,530 in scenario B, to $166,969 in scenario F. In order to compare these costs to standard benchmarks for cost-effectiveness of health interventions, we calculate the cost per DALY saved. Appendix Table D4 presents the calculations for converting reduced HCC and aflatoxicosis incidence into DALYs saved, based on the most recent method published by the World Health Organization (WHO, 2017). The benchmark of one to two times the gross national

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[24] We treat this evidence as speculative because it is based on an outcome at midline that was not pre-specified as a primary study outcome. The study found no impact on child growth at 20-24 months, the pre-specified primary outcome.

[25] We use the March 14, 2018 exchange rate from www.xe.com, which is 101.30 KSh per USD.

income (GNI) per capita per DALY (Shillcutt et al., 2009) implies that interventions in Kenya that cost less than $1,620-$3,240 per DALY saved are cost-effective (World Bank, 2018). Aflatoxin prevention technologies cost between $1,312 and $3,019 per DALY saved (row 35 of Table 5). By the lower benchmark of 1-times-GNI per capita, all of the policy scenarios described are cost-effective except the fully subsidized dryer (columns E and F). However, even the free dryer is cost effective by the 2-times-GNI per capita benchmark.

We also consider the cost effectiveness of aflatoxin control for improving child growth. Dividing the total cost of the subsidy by the number of children under the age of five years in Eastern Kenya, we find that the public cost of deploying these technologies ranges from $3.72 to $11.13 per child (row 36). This translates into a cost per standardized mean difference in length-for-age z-score of $23.33 to $53.71/SMD/child (row 37). We find that based on the available evidence linking aflatoxin exposure to child stunting, all scenarios except for the fully subsidized dryer are more cost-effective than a common intervention for improving child growth—nutrition education—that was recently estimated to cost $30.31/SMD/child (Bhutta et al., 2013).[26]

5.1 Discussion of policy simulations

All of the policies considered above are deemed to be cost-effective interventions for reducing death from aflatoxicosis and HCC. This is consistent with previous research evaluating the cost-effectiveness of aflatoxin control measures in terms of HCC prevention (Wu and Khlangwiset, 2010). In addition, emerging evidence on the role of aflatoxin in child stunting suggests that lower-cost measures to limit exposure to the toxin could be a cost-effective strategy for improving child linear growth in the study region.

We note that the most cost-effective of the simulated policies are scenarios A-D, with similar costs of $1,312 to $1,416 per DALY saved. However, due to limitations in knowledge about the efficacy of the dryer following drying maize cobs on bare ground, we make the optimistic assumption in

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[26] Bhutta et al.estimated a cost of 5.22 Special Drawing Rights (SDR) per child for an intervention that increased LAZ by 0.25 SMD; this converts to $7.59 USD at the March 14, 2018 exchange rate.

scenarios C and D that all dryer users also use plastic barriers. This mechanically increases the effectiveness of the dryer in our simulations. We therefore conclude that the most cost-effective approaches are scenarios A and B.[27]

We further note that while scenario B offers a slight improvement over scenario A, this improvement is unlikely to be worth the effort required to ensure that the existing price premium for safer grain is passed on to producers, nor the potential unintended consequences. A premium that passes through to farmers would require diffusion of low-cost, simple-to-use aflatoxin tests, as well as awareness campaigns to create consumer demand for tested maize. Increased aflatoxin testing would raise the question of how to deal with contaminated maize. In all likelihood, maize above the regulatory limit would not be destroyed as prescribed, but would instead be sold at lower prices to households unable to afford the premium for safer grain. The distributional implications of this approach are likely non-trivial. We therefore conclude that encouraging adoption of aflatoxin mitigation technology through subsidies is preferable (and far more effective) than intervening in the market to expand and promote the transmission of a price premium for aflatoxin-safe maize.

The advantage in cost-effectiveness of subsidies over a price premium in this context stems from the nature of the most cost-effective technology made available to farmers. Drying maize on plastic sheets requires no more effort than drying it on the used woven bags typically employed by farmers for this purpose, and likely reduces effort relative to drying maize on the bare ground due to the greater ease of gathering the maize after drying. This implies a high rate of adoption of this technology for both marketed and home-consumed maize. We further note that cost-effectiveness is actually worsened by the food safety premium when both plastic sheets and the partially or fully subsidized dryer are offered. This arises because dryer adoption by market producers entails significant public cost, while the additional reduction in aflatoxin arising from dryer use is marginal

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[27] Simulations for scenarios C through F may be affected by potentially upward-biased dryer demand estimates due to the offer of subsidized hermetic bags. To bound the impact of this potential bias on our conclusions, we reduce take-up among subsistence farmers by 50% in scenarios C through F. This shifts the range of cost per DALY saved under these scenarios to a lower bound of $1,428 (scenario C) and an upper bound of $3,019 (scenario F), and does not change their rank order. The treatments associated with scenarios A and B did not include this feature and are therefore not affected.

relative to that achieved through the use of plastic sheeting and other practices promoted through training.

6 Conclusions

Produce markets lacking effective regulation or quality certification systems are susceptible to market failures, whereby market producers under-invest in unobservable qualities. This can have significant implications for human health through the contamination of food with biological and chemical hazards.

We provide evidence that the use of low-cost post-harvest practices to improve food safety is generally low in the Kenyan context. Only 1.5% of maize farmers in a sample drawn from one of the world's most notorious aflatoxin hot-spots are undertaking all recommended post-harvest practices to prevent contamination with the toxin, and practices are significantly worse among farmers who produce maize for sale. This is not surprising given the unobservability of food safety attributes in local markets, and the resulting lack of any price premium.

A significant share of food safety hazards originate at the production and post-harvest handling stages. Beyond fungal toxins, sourcing and treatment of irrigation water, safe use of pesticides, and disease management in livestock are all decisions taken by primary producers that have significant implications for human health. We tested two potential policy solutions to this challenge through a randomized field experiment: subsidies for technologies that improve food safety and a price reward for safer food.

The analysis conducted here indicates that a mobile maize dryer for which we elicited farmer demand is not a commercially viable technology without significant subsides. We find that the benefits of adoption generated by such subsidies are unlikely to be sufficient to justify the public cost. In contrast, we find that benefits of adopting plastic sheeting are very large relative to the public cost of subsidizing sheeting, and that subsidies for sheeting increase adoption considerably.

A price premium for aflatoxin-free maize does not significantly impact adoption of plastic sheeting.

It does, however, increase adoption of the dryer, but only increases the share of marketed maize that is mechanically dried from zero to 25%. Further, creating local demand to sustain such a premium would likely require significant public sector investment, as access to rapid, market-based testing for unobservable attributes would be required.

We caution that such an approach is likely to generate (or exacerbate) inequality in food safety, since the poorest households typically consume the lowest-cost foods (Hoffmann and Moser, 2017). It is therefore critical that any expansion in either regulatory enforcement or voluntary testing of food safety attributes is accompanied by efforts to promote technologies that increase quality across the price spectrum. In contrast, technologies such as impermeable drying sheets, which both improve food safety and provide other advantages to producers in terms of reduced effort, cost, or losses, have the potential to generate broadly distributed gains in public health.

We conclude that provision of free impermeable sheets and training on post-harvest practices is a cost-effective public health intervention by standard benchmarks, and the most cost-effective of six policy scenarios combining market incentives and subsidies tested through this experiment.

Disclosure

Neither author, nor any funder of this study, has any personal, professional or financial interest in the promotion or usage of plastic sheeting or drying services, in Kenya or elsewhere.

Tables

Table 1: Farmer characteristics by producer type

	Full Sample	Market Producers	Subsistence Farmers	p-value
Household characteristics				
Market producer	0.43			
	(0.07)			
Household size in adult equivalent	3.59	3.44	3.71	0.01
	(0.08)	(0.10)	(0.08)	
Household head: any secondary school	0.20	0.28	0.15	0.00
	(0.03)	(0.03)	(0.03)	
Wife: any secondary school	0.19	0.26	0.14	0.00
	(0.03)	(0.03)	(0.02)	
Asset Index	0.00	0.51	-0.38	0.00
	(0.12)	(0.11)	(0.11)	
Land owned (acres)	1.76	2.21	1.42	0.00
	(0.18)	(0.18)	(0.14)	
Non-food expenditures (i)	12.22	14.98	10.15	0.00
	(0.94)	(0.83)	(1.04)	
Food consumption value (i)	23.78	26.25	21.92	0.00
	(1.15)	(1.08)	(1.16)	
Consumption of own-produced maize (ii)	1.85	1.68	1.97	0.04
	(0.11)	(0.11)	(0.13)	
Baseline post-harvest practices				
Used a barrier at all drying stages	0.57	0.49	0.64	0.05
	(0.06)	(0.04)	(0.07)	
Used impermeable plastic barrier	0.04	0.03	0.05	0.29
	(0.01)	(0.01)	(0.02)	
Sorted maize	0.37	0.34	0.39	0.21
	(0.02)	(0.03)	(0.02)	
Applied storage chemicals	0.61	0.73	0.51	0.00
	(0.05)	(0.04)	(0.05)	
N	679	291	388	

Note: (i) 100 KSH/adult equivalent/month, winsorized; (ii) KG/Adult equivalent/week Sample includes 679 farmers interviewed at baseline Columns 2 and 3 present the mean values by producer group. Column 4 presents the p-value of the test of equality of means. Bootstrapped standard errors in parentheses, corrected for village clustering. For column 5: * p<.10; ** p<.05; *** p<.01.

Table 2: Sample sizes for analysis

Category	Treatment	Control	Total
Total enrolled at baseline	350	329	679
Total followed up	268	272	540
Of which,			
Cultivated this season	265	269	534
Dried maize this season	**235**	**233**	**468**
Participated in lottery	**236**	..	
Of which,			
Eligible for dryer use (sufficient harvest)	180	..	
Did not participate in lottery	115	..	
For which, reason was			
Insufficient harvest expected	75	..	
Declined to participate	15	..	
Did not attend meeting	24	..	

Note: The rows in bold indicate the analysis samples. Those followed-up who also dried maize in the relevant season are included in the analysis of tarp usage. Some farmers with very small harvests consume maize fresh and harvest as needed, with no intention to dry and store the maize. All lottery participants are included in the analysis of dryer usage. Farmers who expected a harvest of at least 45kg and participated in the lottery but did not have at least 45kg by the time appointments for dryer use were made were ineligible to use the drying service. These farmers are included in the main analysis sample due to the possibility of endogenous selection.

Table 3: Plastic barrier use is increased by free provision

	(1)	(2)	(3)	(4)
Free provision	0.442***	0.412***	0.412***	0.370***
	(0.056)	(0.049)	(0.062)	(0.066)
Free x Sales Incentive		0.063		0.085
		(0.072)		(0.081)
Market Producers			-0.020	-0.016
			(0.042)	(0.042)
Free x Market Producers			0.071	0.106
			(0.074)	(0.100)
Sales Incentive x Market Producers				-0.073
				(0.136)
Controls included	No	No	Yes	Yes
Excluded Group Mean	0.030	0.030	0.034	0.034
Observations	468	468	468	468
Joint significance of hypotheses (p-val)		0.000	0.000	0.000
Effect of free provision or incentive on MP:				
Free+(Market x Free)			0.483***	0.476***
p-val			0.000	0.000
Incentive+(Market x Incentive)				0.012
p-val				0.919
Effect of being an MP in presence of free provision or incentive:				
Market+(Market x Free)			0.050	0.090
p-val			0.409	0.312
Market+(Market x Incentive)				-0.088
p-val				0.536

Note: In all columns, the dependent variable is a binary indicator of using a plastic barrier while drying. Sample is conditional on drying maize in the relevant season. Controls include all variables shown in Table 1. Bootstrapped standard errors in parentheses, corrected for village clustering. * p<.10; ** p<.05; *** p<.01.

Table 4: Cost discounts and sales price incentives increase use of drying service, differentially for market and subsistence producers

		(1)	(2)
a	Market Producers (MP)	-0.395***	-0.316***
		(0.110)	(0.093)
b	Full Discount	0.367***	0.367***
		(0.077)	(0.083)
c	MP x Full Discount	0.137	0.134
		(0.109)	(0.128)
d	Partial Discount	0.251**	0.266**
		(0.125)	(0.108)
e	MP x Partial Discount	0.135	0.157
		(0.182)	(0.181)
h	Incentive	0.005	0.029
		(0.062)	(0.071)
i	MP x Incentive	0.154	0.125
		(0.099)	(0.097)
j	Controls	No	Yes
	Excluded Group Mean	0.316	0.316
	Observations	236	236
	Joint significance of hypotheses (p-val)	0.000	0.000
	Effect of full discount or incentive on MP:		
k	FullDisc+(Market x FullDisc)	0.504***	0.501***
	p-val	0.000	0.000
m	Incen+(Market x Incen)	0.159**	0.154**
	p-val	0.041	0.023
	Effect of being an MP in presence of full discount or incentive:		
n	Market+(Market x FullDisc)	-0.241**	-0.191*
	p-val	0.026	0.063
o	Market+(Market x Incen)	-0.241	-0.185
	p-val	0.148	0.178

Note: Sample includes 236 farmers who participated in the lottery. In both columns, the dependent variable is a binary indicator of attempting to use the dryer. In both columns the excluded category is subsistence farmers offered the dryer without any subsidy or incentive. Controls include all variables shown in Table 1. Bootstrapped standard errors in parentheses, corrected for village clustering. * p<.10; ** p<.05; *** p<.01.

Table 5: Policy simulations for training and plastic tarp & dryer subsidy and incentive schemes

		Training + Free Plastic +					
		No Dryer		**Discounted Dryer**		**Free Dryer**	
R		**No Prem. (A)**	**Premium (B)**	**No Prem. (C)**	**Premium (D)**	**No Prem. (E)**	**Premium (F)**
1	Efficacy: Training + Plastic + Dryer			0.759	0.759	0.759	0.759
2	Efficacy: Training + Plastic	0.701	0.701	0.701	0.701	0.701	0.701
3	Efficacy: Training	0.409	0.409	0.409	0.409	0.409	0.409
	Subsistence Maize						
4	Share maize affected by training at all	0.932	0.932	0.932	0.932	0.932	0.932
5	Share maize affected by training only	0.488	0.488	0.167	0.167	0.014	0.014
6	Share maize affected by training + plastic only	0.444	0.444	0.059	0.059	0.096	0.096
7	Share subsistence farmers using full package*			0.706	0.706	0.822	0.822
8	Proportion of maize dried, conditional on dryer use			0.540	0.540	0.721	0.721
9	Share maize affected by full package			0.381	0.381	0.592	0.592
	Marketed Maize						
10	Share maize affected by training at all	0.931	0.931	0.931	0.931	0.931	0.931
11	Share maize affected by training only	0.431	0.396	0.264	0.231	0.209	0.138
12	Share maize affected by training + plastic only	0.500	0.535	0.222	0.100	0.111	0.103
13	Share market producers using full package*			0.444	0.600	0.611	0.690
14	Net incentive payment in experiment			0	600	0	675
15	Drying cost per KG (KSh)			1.70	1.70	0	0
16	KG sales to earn same incentive at 2 KSh/kg premium			n/a	2000	n/a	337.5
17	Share of market producers selling at least this much			n/a	0.037	n/a	0.263
18	Share of maize produced by these farmers (%)**			0	0.424	0	0.839
19	Simulated share maize affected by full package			0	0.254	0	0.579
20	Simulated share maize affected by training + plastic only			0.667	0.446	0.722	0.214
21	% reduction in contamination of subsistence maize	0.511	0.511	0.627	0.627	0.684	0.684
22	% reduction in contamination of marketed maize	0.527	0.537	0.575	0.600	0.592	0.646
23	AF exposure, stored maize (ng/day/kg bodyweight)	24.06	24.06	18.36	18.36	15.56	15.56
24	AF exposure, purchased maize (ng/day/kg bodyweight)	9.22	9.02	8.27	7.79	7.95	6.90
25	Total exposure through maize (ng/day/kg bodyweight)	33.3	33.1	26.6	26.2	23.5	22.5
26	% Dietary reduction relative to status quo	0.515	0.518	0.612	0.619	0.657	0.673

Table 5 Continued

			No Dryer		**Discounted Dryer**		**Free Dryer**	
			No Prem.	**Premium**	**No Prem.**	**Premium**	**No Prem.**	**Premium**
Q	**R**		**(A)**	**(B)**	**(C)**	**(D)**	**(E)**	**(F)**
4	27	Reduction in aflatoxicosis deaths/yr	10.7	10.8	12.7	12.9	13.7	14.0
	28	Reduction in HCC cases/yr	34.4	34.6	40.8	41.3	43.8	44.9
	29	Standardized mean difference, LAZ	0.159	0.160	0.188	0.191	0.202	0.207
5	30	Cost of training	$767,687	$767,687	$767,687	$767,687	$767,687	$767,687
	31	Cost of subsidizing plastic	$2,519,359	$2,519,359	$2,519,359	$2,519,359	$2,519,359	$2,519,359
	32	Cost of subsidizing dryer	$0	$0	$751,603	$952,109	$4,702,125	$6,539,904
	33	Total cost (USD)	$3,287,046	$3,287,046	$4,038,649	$4,239,156	$7,989,172	$9,826,950
	34	Public cost per life saved (USD)	$72,938	$72,530	$75,435	$78,293	$138,919	$166,969
	35	Public cost per DALY saved (USD)	$1,319	$1,312	$1,364	$1,416	$2,512	$3,019
	36	Public cost/child under 5 years	$3.72	$3.72	$4.57	$4.80	$9.05	$11.13
	37	Public cost per SMD	$23.46	$23.33	$24.26	$25.18	$44.68	$53.71

*We assume that farmers choosing to use the dryer would also use plastic. This may generate an overestimate of the effectiveness for these scenarios.

** We assume that in the absence of any incentive, no marketed maize will receive dryer treatment, even if it only costs time/effort.

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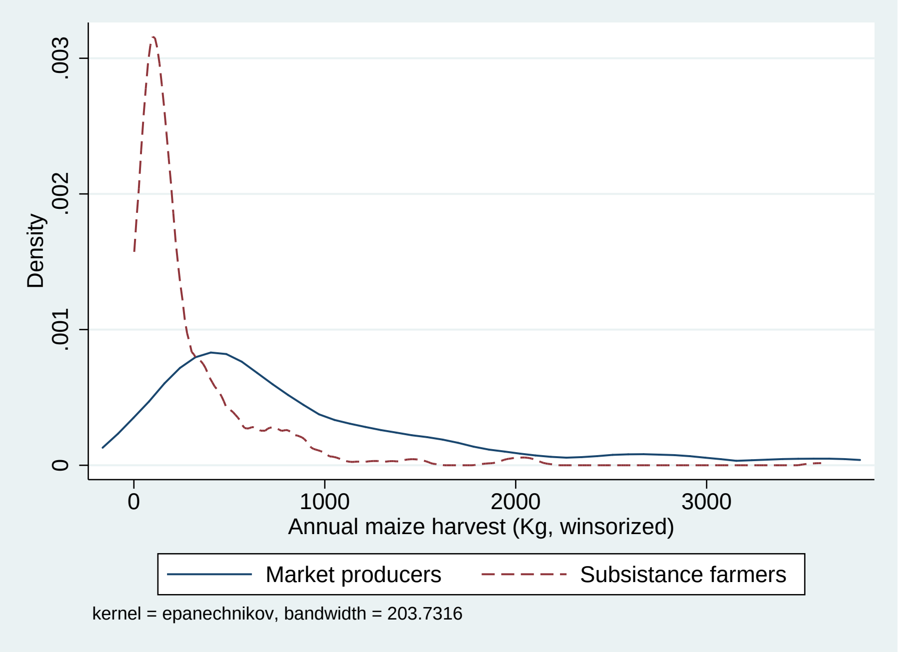
Figures

Figure 1: Harvest size by producer type



Note: harvest sizes are winsorized at the top and bottom 1%

Figure 3: Take-up of plastic sheets by producer type and treatment

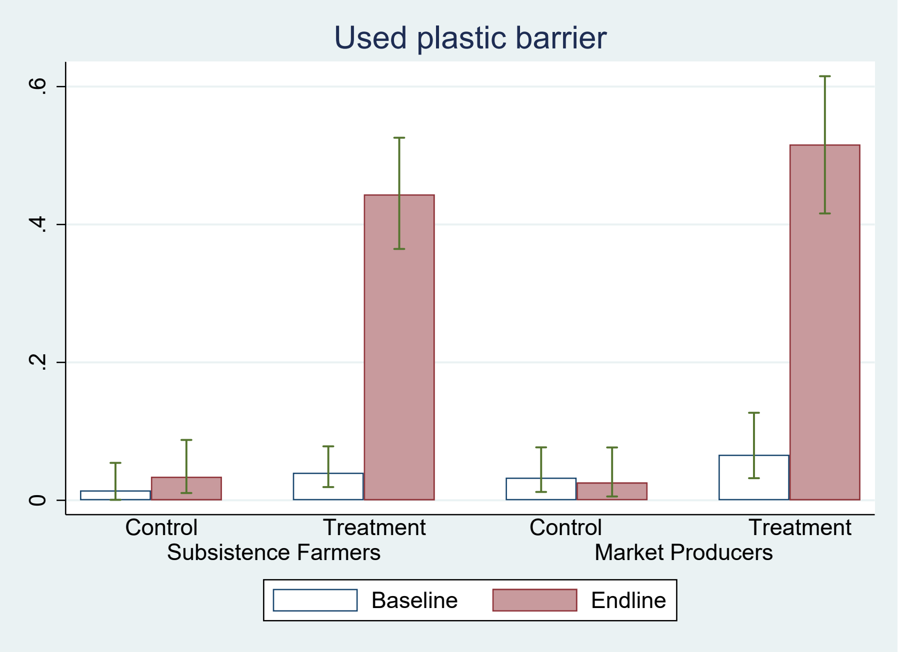
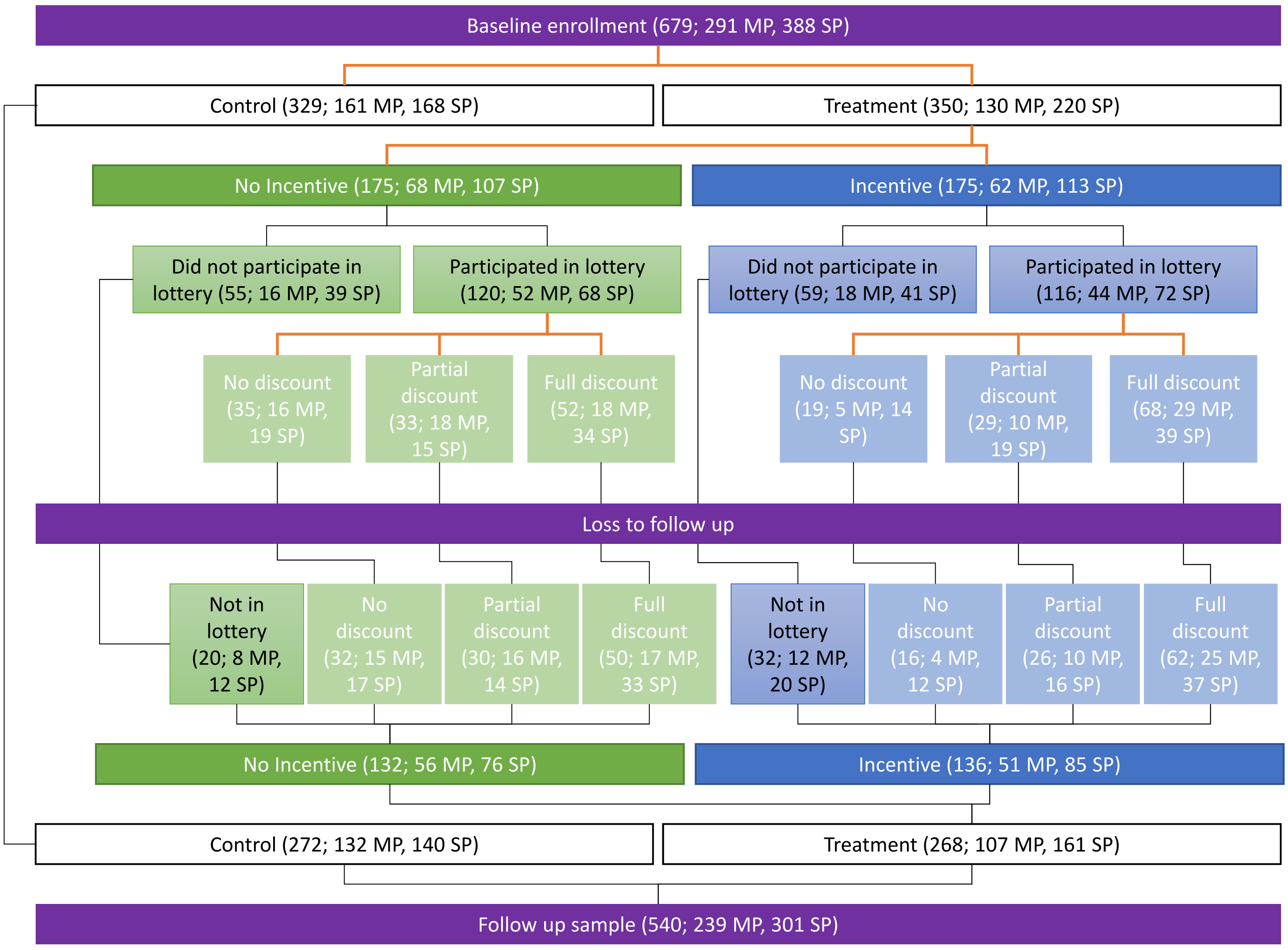


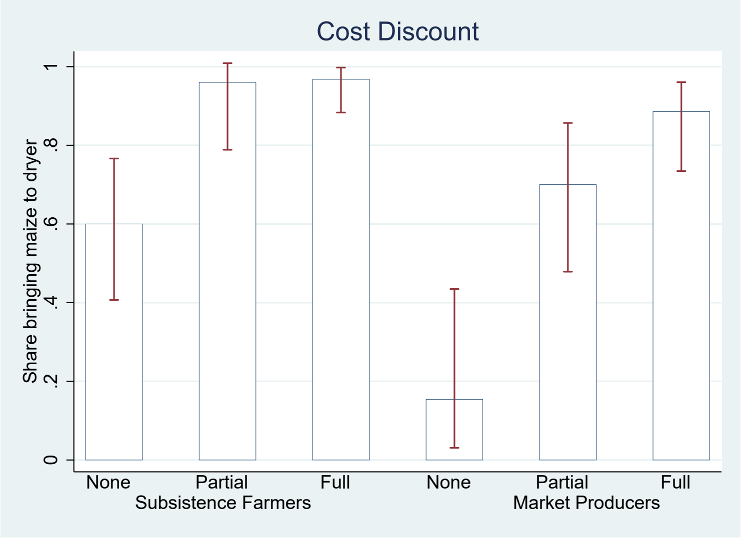
Figure 2: Study Design



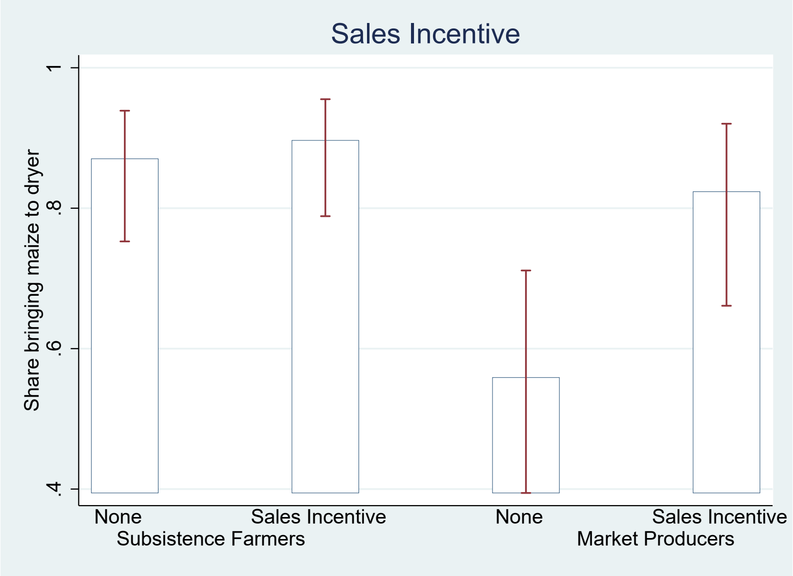
*Bold orange lines indicate random assignment. Full sample size is given first, MP=market producers, SP=subsistence producers.

Figure 4: Take-up of drying service by producer type and treatment

4.A

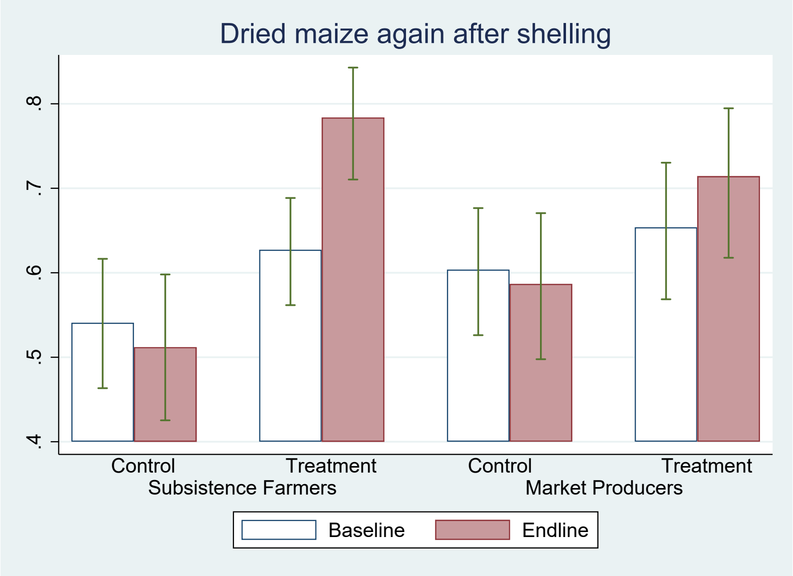


4.B



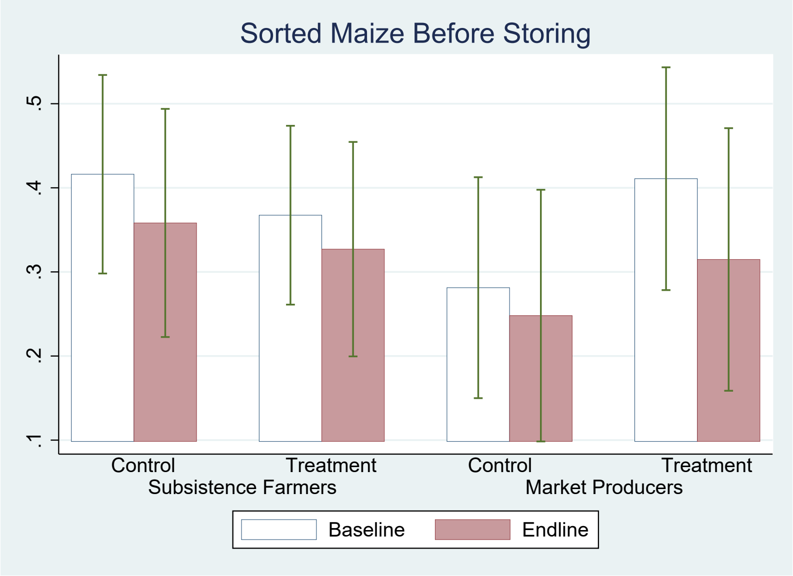
Note: Samples include those who were eligible to use the dryer, which required a minimum of 45kg of maize to operate.

Figure 5: Change in drying maize again after shelling by producer type



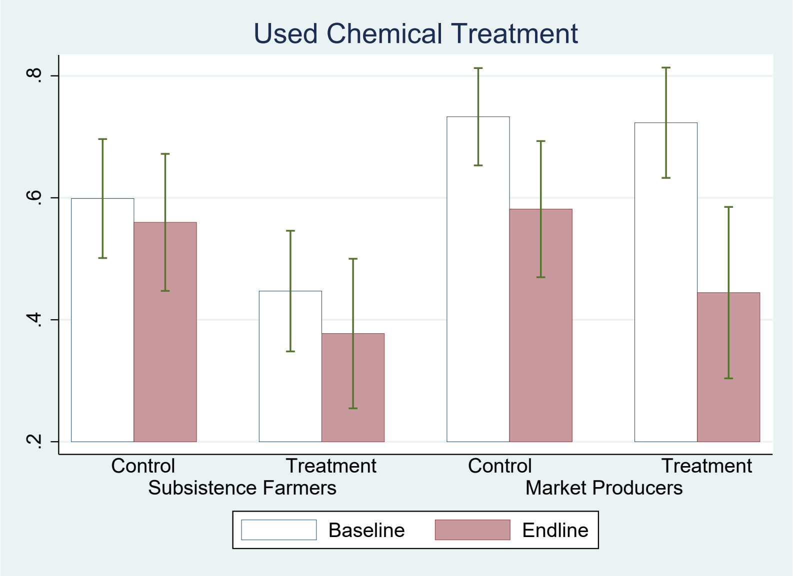
Note: Bars indicate the proportion of the sample who report the practice. Lines indicate the Agresti-Coull approximation of the binomial confidence interval (Agresti and Coull, 1998).

Figure 6: Change in maize sorting by producer type



Note: Bars indicate the proportion of the sample who report the practice. Lines indicate the Agresti-Coull approximation of the binomial confidence interval (Agresti and Coull, 1998).

Figure 7: Change in chemical use by producer type



Note: Bars indicate the proportion of the sample who report the practice. Lines indicate the Agresti-Coull approximation of the binomial confidence interval (Agresti and Coull, 1998).

Appendix

A Attrition

Attrition from the follow-up survey accounts for a loss of 139 farmers, or 20% of the baseline sample. Nearly half of the attrited households (8%) were incorrectly excluded from the follow-up survey because they did not contain a child under 36 months of age. This exclusion error arose (in both treatment and control villages) due to the combination of data collection efforts with another study for which a subset of villages served as joint controls. The remaining attrition is primarily explained by three factors. First, baseline data regarding household location was poor quality. Due to baseline data quality issues, a different data collection company was employed to collect follow-up data, further reducing our ability to locate baseline-enrolled households. Second, follow-up data was collected a full two years after baseline. In this region, households are fairly mobile, and relocations during this time made some households impossible to track. Even among those who were followed up, not all farmers were able to answer questions on drying and storage since some had not cultivated maize in the most recent agricultural season, or had a harvest too small to store any maize. Combined, these categories account for the loss of an additional 72 farmers.

We describe the determinants of attrition from each analysis sample in Table A1. We find that neither assignment to treatment, nor to any of the sub-treatments, predicts attrition (top panel of Table A1). We also test for whether those who attrit from each treatment group are different from those who attrit from the control group based on observable characteristics. In terms of the sample for analysis of drying sheet use, we find that those who attrit from the treatment group have smaller households and a lower probability of the head having attended secondary school, as compared to those who attrit from the control group. Within the treatment group, those who attrit from the incentive arm have lower levels of own-produced maize consumption and lower probability of having used a plastic barrier at baseline compared to attritors in the non-incentive arm.

Finally, in terms of whether or not a household participated in the lottery (and was therefore included in the analysis of dryer use), households that attrited from the incentive treatment have larger households, higher educational attainment, were more likely to have used a barrier at all stages of drying at baseline, and were less likely to have used a plastic barrier, compared to those who attrited from the non-incentive treatment group. We discuss how differences in the correlates of attrition by treatment group may affect our estimates in sections 3.2.1 and 3.2.2.

Table A1: Attrition analysis

Dep Var:	No data on tarp use		Not in lottery
Definition of treatment:	Free tarp	Incentive	Incentive
Sample:	All	Treat group	Treat group
Treatment	0.037	0.029	0.023
	(0.100)	(0.039)	(0.049)
N	679	350	350
Interactions of baseline characteristics with treatment			
Market Producer	-0.068	0.048	0.122
	(0.106)	(0.113)	(0.079)
Household size in adult equivalent	-0.045*	0.042	0.086***
	(0.026)	(0.035)	(0.031)
Household head: any secondary school	-0.219**	0.150	0.232**
	(0.095)	(0.129)	(0.109)
Wife: any secondary school	0.103	-0.079	-0.162
	(0.102)	(0.164)	(0.099)
Asset Index	0.006	-0.008	-0.006
	(0.022)	(0.032)	(0.044)
Land owned (acres)	0.026	0.017	-0.003
	(0.033)	(0.037)	(0.017)
Non-food expenditures (i)	-0.004	-0.003	-0.007
	(0.003)	(0.004)	(0.004)
Food consumption value (i)	-0.003	0.005	0.002
	(0.004)	(0.005)	(0.005)
Own-produced maize consumption (ii)	-0.011	-0.029*	-0.049
	(0.018)	(0.016)	(0.031)
Always used barrier for drying (any type)	-0.149	0.104	0.176**
	(0.104)	(0.091)	(0.084)
Ever used plastic barrier	-0.100	-0.446*	-0.528**
	(0.297)	(0.230)	(0.252)
Sorted maize	-0.014	0.037	0.083
	(0.061)	(0.092)	(0.124)
Chemical Use	0.079	0.033	0.091
	(0.079)	(0.090)	(0.107)
Excluded Group Mean	0.173	0.246	0.246
Observations	679	350	350

Note: Top panel shows $\hat{\beta}_0$ from $Attrit_i = \alpha_0 + \beta_0 Treat_i + \varepsilon_i$. Lower panel shows the $\hat{\delta}$ vector of coefficients from $Attrit_i = \alpha_0 + \beta_0 Treat_i + X_i\gamma + Treat_i X_i \delta + \varepsilon_i$, where $X_i$is a vector of household characteristics and post-harvest practices from baseline. The variable used for $Attrit_i$ is shown the top column header. The variable used for $Treat_i$ is shown in the lower column header. The sample employed is noted in the lowest column header. Bootstrapped standard errors, corrected for village clustering, are shown in parenthesis. Significance at the * 10%, ** 5%, and *** 1% levels.

B Additional Tables

Table B1: Baseline balance

	Treatment group			Incentive			Discount			
	No	Yes	p-value	No	Yes	p-value	None	Partial	Full	p-value
Market Producer	0.49	0.37	0.35	0.39	0.35	0.35	0.39	0.45	0.39	0.73
	(0.08)	(0.09)		(0.10)	(0.09)		(0.12)	(0.12)	(0.13)	
Household size in adult equivalent	3.58	3.60	0.91	3.56	3.64	0.92	3.54	3.45	3.56	0.88
	(0.13)	(0.11)		(0.14)	(0.16)		(0.18)	(0.19)	(0.11)	
Household head: any secondary school	0.20	0.20	0.99	0.17	0.24	0.31	0.24	0.24	0.24	0.78
	(0.05)	(0.04)		(0.04)	(0.06)		(0.07)	(0.09)	(0.06)	
Wife: any secondary school	0.18	0.20	0.77	0.21	0.19	0.86	0.19	0.24	0.25	0.33
	(0.04)	(0.05)		(0.04)	(0.06)		(0.06)	(0.08)	(0.05)	
Asset Index	0.07	-0.06	0.62	-0.11	-0.01	0.69	-0.19	0.22	-0.03	0.66
	(0.19)	(0.18)		(0.20)	(0.18)		(0.31)	(0.37)	(0.20)	
Land owned (acres)	1.93	1.60	0.35	1.54	1.66	0.20	1.55	1.43	1.66	0.25
	(0.28)	(0.21)		(0.23)	(0.18)		(0.30)	(0.29)	(0.28)	
Non-food expenditures (i)	12.52	11.94	0.78	11.35	12.52	0.58	12.97	11.47	15.28	0.00
	(1.47)	(1.35)		(1.36)	(1.59)		(1.80)	(1.46)	(1.35)	
Food consumption value (i)	23.14	24.37	0.59	24.22	24.53	0.83	27.23	25.25	24.93	0.39
	(1.87)	(1.21)		(1.56)	(1.26)		(2.16)	(1.70)	(1.39)	
Own-produced maize consumption (ii)	1.79	1.90	0.62	2.07	1.74	0.02	1.95	2.22	1.87	0.18
	(0.18)	(0.14)		(0.12)	(0.19)		(0.19)	(0.22)	(0.13)	
Baseline post-harvest practices										
Always used barrier while drying (any type)	0.54	0.60	0.52	0.57	0.64	0.18	0.56	0.62	0.66	0.55
	(0.05)	(0.09)		(0.12)	(0.07)		(0.14)	(0.11)	(0.12)	
Ever used plastic barrier for drying	0.02	0.05	0.25	0.04	0.06	0.23	0.06	0.03	0.04	0.80
	(0.01)	(0.02)		(0.03)	(0.02)		(0.03)	(0.03)	(0.02)	
Sorted maize	0.35	0.38	0.32	0.38	0.39	0.60	0.38	0.38	0.36	0.99
	(0.03)	(0.02)		(0.04)	(0.03)		(0.08)	(0.06)	(0.03)	
Chemical Use	0.67	0.55	0.14	0.56	0.54	0.33	0.57	0.52	0.58	0.81
	(0.05)	(0.06)		(0.05)	(0.08)		(0.11)	(0.13)	(0.04)	
N	329	350		175	175		54	62	120	

Bootstrapped standard errors, corrected for village clustering, are shown in parentheses; p-vales are shown for tests of joint orthogonality between the preceding columns.

Table A2: Cost discounts and sales price incentives increase use of drying service, differentially for market and subsistence producers: Eligible farmers only

		(1)	(2)
a	Market Producers (MP)	-0.480***	-0.405***
		(0.122)	(0.121)
b	Full Discount	0.367***	0.370***
		(0.115)	(0.110)
c	MP x Full Discount	0.314**	0.320
		(0.144)	(0.180)
d	Partial Discount	0.359*	0.360**
		(0.160)	(0.145)
e	MP x Partial Discount	0.188	0.212
		(0.266)	(0.298)
h	Incentive	0.014	0.034
		(0.057)	(0.071)
i	MP x Incentive	0.119	0.119
		(0.076)	(0.104)
j	Controls	No	Yes
	Excluded Group Mean	0.462	0.462
	Observations	180	180
	Joint significance of hypotheses (p-val)	0.000	0.000
	Effect of full discount or incentive on MP:		
k	FullDisc+(Market x FullDisc)	0.682***	0.690***
	p-val	0.000	0.000
m	Incen+(Market x Incen)	0.133	0.152
	p-val	0.161	0.182
	Effect of being an MP in presence of full discount or incentive:		
n	Market+(Market x FullDisc)	-0.166**	-0.084
	p-val	0.035	0.274
o	Market+(Market x Incen)	-0.362**	-0.286
	p-val	0.018	0.157

Note: Analog to Table 4, but excluding farmers who participated in the lottery but were ultimately ineligible to use the dryer due to low harvest. Bootstrapped standard errors, corrected for village clustering, are shown in parentheses. Significance at the * 10%, ** 5%, and *** 1% levels.

C Details on costs and feasibility of interventions at scale

We assume that promotion of both the drying service and plastic sheeting would require village-level meetings with farmers. Based on study costs, we estimate that two meetings attended by 25 farmers each can be held each day, at a cost of \$85 US (\$60 for vehicle rental and \$25 in wages) per day. We assume that these promotions occur once every two years, and include plastic sheet distribution.[28] We then multiply the cost of training by 1.18, the marginal cost of public funds in Kenya as estimated by Auriol and Warlters (2012), and apply the five-year average of the one-year Kenya bond rate (0.047) as the social discount rate to account for the fact that benefits of this investment accrue over two years Warusawitharana (2014). Finally, we multiply the per-farmer, per-year cost of promotion and distribution (\$1.10 US) by the total number of farmers in Eastern Kenya (697,657).[29] This comes to a total training cost of \$767,687 US for the region.

The costs for subsidizing the provision of plastic sheeting and drying services are presented in table 4 and the assumptions for these are presented in table C1. The cost of providing fully subsidized plastic sheeting is based on the current cost of 750 gauge plastic in Meru town. We assume that the 14.6 meter squared pieces of sheeting provided through the study are sufficient to dry 600 kg over the course of the year (less each season), and last for two years (four agricultural seasons). Many farmers produce less maize than this; we estimate the mean kg dried per sheet annually to be 377 kg, using the baseline harvest distribution in the study sample. Multiplying the 416 KSh material cost of sheeting per farmer by the marginal cost of public funds and social discount rate as above, and then dividing by the amount of maize dried over the two-year lifespan of the sheets yields a cost per kg of 0.71 KSh., equivalent to approximately 0.007 USD. This is multiplied by regional maize production and the proportion of study farmers who attended training sessions, resulting in a total public cost of \$2,519,359.

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[28] Plastic sheets are assumed to develop tears, rendering them less effective after two years of use. Refresher trainings may also be required to remind farmers of good practices after this interval; a similar study testing the impact of village-level training and tarp provision on aflatoxin in Ghana found impacts two years post-intervention (Hoffmann et al., 2018b).

[29] This is estimated by dividing the region's total average annual maize production by of 383,356 metric tonnes (Ministry of Agriculture, 2015) by mean per-farmer production in our sample (549 kg).

Equipment and operating costs of the mobile dryer are taken from ACDI-VOCA's Aflastop project, which designed the dryer and tested its commercial viability (personal communication, Marius Rossouw, April 7, 2016). We assume the useful life of the dryer is five years, and that it is used for 30 days per year (15 for each season). We apply the Kenya bond rate as the social discount rate, compounding over the five-year dryer lifespan, and the (one-time) marginal cost of public funds to calculate the full cost of the capital investment in the dryer. This full capital cost is then converted to a daily cost by dividing by the number of days the dryer is used over five years. Annual maintenance costs are assumed to be 15% of the dryer cost before accounting for the cost of capital, and are divided by the number of operational days per year to arrive at a daily maintenance cost. We model both a partial dryer subsidy, in which only the capital cost of the dryer is covered by public funds and operating expenses are covered by user fees, and full subsidization. Under full subsidization, the marginal cost of public funds is also applied to the variable cost of drying maize. Finally, we assume that management of subsidies entails personnel costs of 2,500 KSh per day to manage either the operations of 10 fully subsidized mobile dryers, or the disbursement of 3 capital subsidies per month. Assuming an average of 1250 kg (2.5 batches of 500 kg) maize dried per day, we arrive at cost of 2.93 KSh per kg to fully subsidize the mobile dryer, and 0.73 per kg for a partial subsidy covering the capital cost. Assumptions for these calculation are presented in Appendix Table C1.

At the full private operating cost of the drying service, including the the opportunity cost of the capital investment, we estimate the break-even charge for drying maize at 2.35 KSh/kg. [30]

At the partially subsidized drying cost (including free plastic sheets), we estimate that the cost to the farmer is 1.7 KSh per kg dried. A market producer's return on investment in drying would thus be 0.3 KSh/kg under a 2 KSh/kg price premium. In the experiment, the maximum amount of maize a farmer could sell at the premium price was capped at (the very low level of) 45 kg, and the premium was set at (the very high level of) 15 KSh/kg. To model the level of adoption triggered by

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[30] We use the weighted average lending interest rate of commercial banks in Kenya, minus inflation rate over the following 12 months, for the 5 year period up to Feb 2017, to estimate the cost of private capital at 10.2%. This rate is compounded over the five-year investment in the dryer.

Table C1: Assumptions for tarp and dryer subsidy costing

General assumptions	
KSh to USD exchange rate	101.2
Marginal cost of public funds	0.18
Rate of return on private capital	0.102
Social discount (SDR) for public resources	0.047

Technology assumptions	**Mobile Dryer**	**Plastic Sheet**	**Sheets + Dryer**
	A	**B**	**C**
Operating days / year	30	n/a	
Useful life (years)	5	2	
KG dried per day or per drying sheet	1250	377	
Operating hours / day	7	n/a	
Capital costs			
Cost of equipment	75,000	416	
Total cost of capital (@ private lending rate)	121,975	416	
Total cost of equipment (incl. MCPF + SDR)	111,570	539	
Daily operating costs			
Daily private cost of capital	813	n/a	
Daily public cost of capital (social discount rate)	744	n/a	
Daily maintenance & repairs	375	n/a	
Labor costs (daily)	1,000	n/a	
Fuel cost / operating day @ 50 KSh / hour	350	n/a	
Transport cost / operating day	400	n/a	
Subsidy management costs			
Capital subsidies disbursed per team per month	3		
Operating subsidies managed per team	10		
Daily cost of management team	2500		
Capital subsidies management cost per KG	0.133		
Operating subsidies management cost per KG	0.200		
Cost to farmer / KG			
Private provision model	2.35	0.55	2.90
Partial subsidy	1.70	n/a	1.70
Subsidy cost / KG			
Total subsidy	2.93	0.71	3.65
Partial subsidy	0.73	n/a	1.44

Note: Costs are in KSh.

a 2 KSh/kg premium, we consider the total return to adopting the dryer offered to farmers assigned to the incentive treatment of the experiment. Farmers who dried and sold 45 kg through the study could earn a total incentive payment of 675 KSh. At the intermediate price point of 1.67 KSh/kg charged in the experiment (75 KSh to dry 45 kg), this yields a total return of 600 KSh on the decision to adopt. Under the full dryer subsidy, farmers kept the entire incentive payment of 675 KSh. Dividing this amount by the full 2 KSh/kg premium, farmers who sold at least 337.5 kg (26.3% of the sample) could earn the equivalent incentive under a realistic per-kg premium.

D Policy Simulation Details

This appendix discusses in detail the calculation behind the figures in Table 5. Row numbers refer to that table.

D.1 How much does the technology reduce contamination in maize?

To assess the level of aflatoxin reduction due to the combined use of plastic drying sheets and the mobile maize dryer, we rely on published evidence. Kaaya and Kyamuhangire (2010) find that at three months of storage, maize that was dried using a biomass dryer similar to the one employed in this study reduced aflatoxin by 85%, relative to maize dried on the bare ground. This is comparable to receiving training and using both the plastic sheets and the mobile dryer because the maize studied by Kaaya and Kyamuhangire (KK) was handled by skilled staff, placed directly in the dryer prior to shelling and did not come into contact with the soil. KK also report month-specific levels of aflatoxin in their experiment, which we use to estimate the monthly level of contamination in both status quo and maize dried using the mobile dryer.[31] Averaging the month-specific reduction levels over KK's six month study yields an average reduction of 75.9% over the course of a full year with two harvest seasons (row 1).

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[31] see Appendix Table D1

Unfortunately, KK do not disaggregate the effects of preventing contact with the soil and use of the dryer. To estimate the efficacy of training and use of plastic drying sheets without the dryer, we rely on evidence from Pretari et al. (2019), who use data from the same experiment described in this paper.[32] Their findings suggest that maize grown by farmers who attended the training and used plastic sheeting for drying (but did not use the dryer) had aflatoxin contamination at 3 months after harvest that was 78% lower than maize grown by farmers assigned to the control group, a difference that is significant at the 1% level. Relying on the relative month-specific reductions reported by KK, this extrapolates to an average reduction of 70% over the course of a year (row 2).

The results reported by Pretari et al. also suggest that a significant part of the estimated impact was due to the training itself, as those attending the training (and not using the plastic or the dryer) had contamination that was 41% lower than control farmers (extrapolated average for one year; row 3). However, as few farmers in this category had maize available for testing 3 months after harvest, the difference is not statistically significant.We therefore do not simulate the impacts of providing training alone.

D.2 What is the expected level of technology adoption?

We model adoption of training only, training and plastic barriers, and the full package of training, plastic and the dryer. These are modeled as the share of maize affected, separately for subsistence and marketed maize. We apply the adoption rates of subsistence farmers in the experiment to subsistence maize (including the maize produced and consumed by farmers who also sell).

Among subsistence farmers, 93.2% of those invited to a training session attended.[33] If a farmer attended the training or used a plastic barrier while drying, we assume that the benefits of this

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[32] Where possible, we use results from KK rather than Pretari et al. because the former are experimental, whereas the latter are based on farmers' decisions to use the technologies offered, which could potentially introduce bias. However, because Pretari et al. provide the only direct evidence of the relative contributions of drying on plastic sheets and use of the mobile dryer, we use their results to estimate the impact of drying on sheets without use of the mobile dryer.

[33] This figure is constant across columns as the content of the meeting (regarding discounts and incentives) was not disclosed to participants in advance and so could not have determined attendance.

knowledge or practice applied to all of the maize that s/he produced, so that the share of maize affected is equal to the share of farmers taking up (rows 4-6). For the dryer, we multiply farmer-level take-up (row 7) by the average share of maize harvest brought to the dryer, conditional on bringing any (row 8) to calculate the share of maize affected by the full package (row 9). Given that subsistence farmers would be unaffected by a market price premium, take-up for these farmers does not vary by premium vs. no-premium scenarios.

For marketed maize, we similarly apply the share of market producers who attended the training or used a plastic barrier as the share of marketed maize affected by these technologies (rows 10-12).[34] In row 13 we present the share of market producers who used the dryer at all as the share of farmers using the full package. Note that we assume here that any farmer choosing to use the dryer would also use the plastic.[35] We note that this assumption mechanically increases the estimated effectiveness of subsidizing the dryer; a point discussed in section 5.1.

Modeling the impact of the price premium on the share of marketed maize to which the dryer is applied is more complex. As described in section 4, only relatively large-scale producers would stand to earn a profit equal to the incentive payment offered through the experiment. While smaller-scale farmers could earn a smaller profit through dryer use, we do not have information on the level of adoption when the total payoff is below this value. We take a conservative approach, assuming that due to the fixed costs associated with arranging for dryer use, market producers who stand to earn a profit less than that offered through the experiment do not use the dryer. We calculate the proportion of farmers in our sample who sold enough maize to earn the experimental bonus (row 17), and the proportion of maize marketed by sample farmers that was sold by this subset (row 18). We then multiply this proportion by the observed adoption rate among market producers at the partially subsidized and zero price (row 13), to estimate the share of marketed maize affected by the full package of technologies (row 19). Under our conservative assumption that only relatively

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[34] While the number of observations is small, Pretari et al. (2019) find no difference in contamination levels between maize stored for sale and that stored for home consumption by farmers provided with tarps and training.

[35] This assumption is required because we have no information regarding the efficacy of the dryer in conditions where the maize has been dried on bare ground. This category exists in Pretari et al., but the size of the group is far too small to give a reliable estimate of efficacy.

large farmers find it worthwhile to adopt the maize dryer under a per-kg premium, fewer farmers use the dryer than observed in the experiment. We assume that farmers who used the dryer in the experiment, but whose production is too low to earn the incentive offered through the experiment under a per-kg incentive, instead make use of only training and plastic. Therefore, rather than employing the observed share shown in row 12, we add to this the difference between rows 19 and 13, yielding the simulated share (row 20).

D.3 What are the expected changes in dietary aflatoxin exposure?

In order to answer this question, we first calculate the percentage reduction in aflatoxin contamination in both stored and purchased maize that arises from the adoption modeled in section D.2. We multiply the efficacy rates in rows 1-3 by the share (or simulated share where applicable) of maize affected by each technology group and sum these products, separately for subsistence and marketed maize (rows 21 and 22).[36]

We next calculate the *status quo* aflatoxin exposure through maize in this region. This requires information on monthly consumption of maize from farmers' own stores and from the market, as the level of aflatoxin varies over the course of the year in maize, and depends on mitigation practices by subsistence and market producers. Table D1 provides details of these calculations.

Maize consumption is measured using data collected during three rounds of interviews, approximately 4 months apart, for a sample that includes both those households involved in this study, and those involved in a separate study for which recruitment criteria were similar, as well as monthly reports of maize purchases collected as part of the latter study.[37] This data is presented in rows A and B. The average household consumes 23.7 kg of maize per month over the course of the

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[36] We assume here that the region is autarkic in maize, so the level of contamination in maize sold by farmers is equal to the level in maize procured from the market. The high transport costs of maize from other maize-exporting regions make this assumption reasonable.

[37] Villages for the two studies were randomly drawn from maize-growing villages in Meru and Tharaka-Nithi counties. Households were eligible to participate in the present study if they contained at least one child under the age of two, while those eligible for the other study had to include a woman who was in the third trimester of pregnancy at the time of enrollment. The protocol for the other study is described in Hoffmann et al. (2015).

year, and 71.4% of this is from their own production and storage. To estimate *status quo* aflatoxin exposure from maize consumption, we use the mean level of aflatoxin detected in maize stored by control group households three months after harvest (18.5 ppb) and extrapolate contamination in other months using the findings of KK regarding the monthly change in aflatoxin contamination in ground-dried maize (row D). Month-specific estimates of aflatoxin levels in the study region under *status quo* post-harvest practices are shown in row K.

We apply these month-specific contamination rates to total monthly maize consumption, and assume an average body weight of 70kg per adult equivalent, to calculate *status quo* exposure from stored maize (49.2 ng/kg/day, row L) and purchased maize (19.5 ng/kg/day, row M).[38] Multiplying the reductions from rows 21 and 22 in Table 5 by the status quo exposure levels from Table D1, we present the aflatoxin exposure from stored and purchased maize in rows 23 and 24 of Table 5, respectively. The total reduction in dietary aflatoxin exposure from maize is shown in row 26.

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[38] Here we assume that the maize stored by households and maize purchased in the market is equally contaminated. Data collected by the authors for a companion study in the same region supports this assumptionHoffmann et al. (2015).

Table D1: Aflatoxin Exposure Calculations

		Feb **(1)**	Mar **(2)**	Apr **(3)**	May **(4)**	Jun **(5)**	Jul **(6)**	Aug **(7)**	Sep **(8)**	Oct **(9)**	Nov **(10)**	Dec **(11)**	Jan **(12)**	Mean **(13)**	Per day **(14)**
HH maize consumption															
Own produced (kg)	**A**	20.3	26.7	25.9	25.1	17.6	18.8	19.2	11.5	11.9	9.4	6.9	10.2		0.557
Purchased maize (kg)	**B**	4.8	4.0	4.8	2.6	7.1	5.9	5.5	7.8	7.4	9.9	12.5	9.1		0.223
Maize contamination															
Months since harvest	**C**	0	1	2	3	4	5	6	0	1	2	3	4		
AF: bare ground drying (PPB)[i]	**D**	1.67	2.27	5.0	9.0	17.5	25.7	32.5	1.67	2.27	5.0	9.0	17.47		
Relative to 3mo post-harvest	**E**	19%	25%	56%	100%	194%	285%	361%	19%	25%	56%	100%	194%		
AF: dried in dryer (PPB)[i]	**F**	0.50	0.83	0.87	1.33	2.23	7.67	11.83	0.50	0.83	0.87	1.33	2.23		
Reduction: train.+barrier+dryer	**G**	70%	63%	83%	85%	87%	70%	64%	70%	63%	83%	85%	87%	**75.9%**	
Relative to 3mo post-harvest	**H**	82%	74%	97%	100%	102%	82%	75%	82%	74%	97%	100%	102%		
Reduction: training	**I**	38%	34%	44%	**46%**	47%	38%	34%	38%	34%	44%	46%	47%	**40.9%**	
Reduction: training + barrier	**J**	65%	59%	76%	**79%**	81%	65%	59%	65%	59%	76%	79%	81%	**70.1%**	
Status quo exposure															
Status quo PPB[ii]	**K**	3.4	4.7	10.3	**18.5**	35.9	52.8	66.8	3.4	4.7	10.3	18.5	35.9		
Subsistence consump. (ng/kg) [iii]	**L**	277	495	1059	1848	2507	3938	5098	157	222	384	504	1457		**49.2**
Market consumption (ng/kg)[iv]	**M**	65	75	197	190	1017	1241	1459	106	137	405	916	1300		**19.5**
Total consumption (ng/kg)	**N**	342	570	1256	2038	3525	5179	6557	264	358	789	1421	2757		**68.6**

Notes: (i) Kaaya and Kyamuhangire (2010); (ii) extrapolated based on months since harvest using [E x J4]; J4 was measured in our data; (iii) [A x J x 1000 / (kg/HH)]; (iv) [B x J x 1000 / (kg/HH)]; (v) [K x G]; (vi) [L x G]; (vii) [K x H]; (viii) [L x H]

D.4 What is the relationship between dietary aflatoxin exposure and health outcomes?

We combine cancer potency estimates for aflatoxin (WHO, 1998) and *status quo* exposure levels reported in Table D1 to estimate the annual incidence of HCC in Eastern Kenya due to aflatoxin exposure (see Appendix Table D3). The contribution of aflatoxin exposure to the risk of developing HCC is 30 times greater for individuals infected with hepatitis B virus than others (WHO, 1998). As previous studies report estimates of hepatitis B prevalence in Eastern Kenya separately for HIV positive and HIV negative individuals (Ly et al., 2016; Muriuki et al., 2013), we also employ estimates of HIV prevalence in Eastern Kenya (Ministry of Health, Kenya, 2013), to calculate the overall hepatitis B rate. Multiplying UNICEF's 2018 population estimate for Eastern Kenya[39] by the calculated HCC incidence, we estimate that dietary aflatoxin exposure through maize causes 66.7 HCC cases in the region each year. Based on the estimated reductions in exposure, we find that between 34 and 45 of these cases could be prevented annually through aflatoxin mitigation (row 28, Table 5).

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[39] https://data.humdata.org/dataset/kenya-population-projection-by-county-2009-2018-and-subcounty-2015

Table D2: Aflatoxicosis Outbreaks

Year	Location	Deaths		Source
1981	Machakos	12		Ngindu et al. (1982)
1987	Meru North	3		Wangia (2017)
2001	Meru	16		Wangia (2017)
2003	Eastern	68		Muthomi (2014)
2004	Thika/Makueni/Kitui	125		Lewis et al. (2005)
2005	Makueni/Kitui	35		Githanga and Awuor (2016)
2006	Makueni/Kitui	21		Githanga and Awuor (2016)
2007	Makueni/Kitui	21		Muthomi (2014)
2008	Eastern	2		Muthomi (2014)
2010	Makueni/Kitui	3		Muthomi (2014)
2014	Kajiado (not eastern)	10		Githanga and Awuor (2016)
1981-2014	**Total**	**316**	**9.3**	per year
2001-2014	**Total**	**301**	**21.5**	per year
2001-2014	**Eastern Total**	**291**	**20.8**	per year

Table D3: Health burden calculations

D3.A

Disease status	Proportion of population in Eastern Kenya (from table B, below)	Aflatoxin cancer potency (IPCS and WHO, 1998)	Estimated annual HCC cases, Eastern Kenya
HBV-, HIV-	0.946	0.01	40.6
HBV+, HIV-	0.017	0.30	21.7
HBV-, HIV+	0.035	0.01	1.5
HBV+, HIV+	0.002	0.30	2.9
Total	1.0	n/a	66.7

D3.B

Disease	Prevalence	Population	Data source
Hepatitis B virus	0.018	HIV- adults, Eastern Kenya	National AIDS and STI Control Programme, 2013
Hepatitis B virus	0.060	HIV patients, Nairobi	Muriuki et al., 2013
HIV	0.037	15-64 adults, Eastern Kenya	Ly et al., 2016

Note: For each row in table D3.A, we multiply the total estimated population of Eastern Kenya in 2018 (6.255 million, according to Unicef projections - see https://data.humdata.org/dataset/kenya-population-projection-by-county-2009-2018-and-subcounty-2015) by the proportion of the population in that category, the estimated average daily aflatoxin exposure per KG body weight based on study data, and the cancer potency factors (cases per 100,000 per ng/KG exposure), to estimate the number of HCC cases due to aflatoxin in the absence of any intervention. Regionally representative statistics on HBV prevalence are only available for the HIV negative population in Eastern Kenya. We use HBV prevalence reported for a group of HIV positive patients recruited from Nairobi health centers for the HIV positive share of the population, as this is the location closest to the study area for which an HBV prevalence rate among HIV-positive individuals is available.

D.5 How does cost-effectiveness compare to other interventions?

The public costs of subsidizing the training, plastic sheeting, and drying technology, as discussed in section 4, are shown in USD in rows 30, 31, and 32, respectively.[40] To calculate the total subsidy costs of providing plastic sheets and the mobile drying service, we employ the per-kg cost of of each, presented in Table C1, and multiply these unit costs by the estimated volume of maize for which the technology is provided (in the case of plastic sheets) or to which it is applied (in the case of the dryer). We assume that sufficient plastic sheeting is provided to dry the maize grown by the 93% of subsistence and market producers who attend training meetings, regardless of whether these farmers actually use the sheets for drying maize. We estimate the total volume of maize dried by multiplying the shares of subsistence and marketed maize dried (rows 9 and 19) by their respective diet shares, and then by total regional production.[41]

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[40] We use the March 14, 2018 exchange rate from www.xe.com, which is 101.30 KSh per USD.

[41] Here we again rely on the simplifying assumption that Eastern Kenya is autarkic in maize.

Table D4: Converting lives saved to disability adjusted life years (DALYs) saved

Aflatoxicosis		**Notes**
Mean age of diagnosis in Kenya	22.5	(Azziz-Baumgartner et al., 2005)
Median yrs lived from diagnosis in Kenya	0.185	18 of 40 cases died w/in 2 mths of diagnosis (Azziz-Baumgartner et al., 2005)
DALY weight of living with disease	0.540	disability weight for terminal stage liver disease (Salomon et al., 2015)
YLL, based on WHO life expectancy	69.57	employs standard loss function [WHO, 2017, table 2.1]
YLL, based on Kenya life expectancy	39.44	employs Kenyan life expectancy (62.13, World Bank, 2017)
YLD	0.10	0.185*0.540 (WHO, 2017)
DALY cost per death	69.67	YLL+YLD (WHO, 2017)

Hepatocellular Carcinoma		
Mean age of diagnosis in Kenya	40	(Mwangi and Gatei, 1993)
Median yrs lived from diagnosis in Kenya	2.941	Imputed, assuming linearity over time (Ministry of Health, 2013)
DALY weight of living with disease	0.372	(.288*.333) + (.540*.667) (Salomon et al., 2015)
YLL, based on WHO life expectancy	49.73	employs standard loss function [WHO, 2017, table 2.1]
YLL, based on Kenya life expectancy	19.19	employs Kenyan life expectancy (62.13, World Bank, 2017)
YLD	1.09	2.941*0.372 (WHO, 2017)
DALY cost per death	50.82	YLL+YLD (WHO, 2017)