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ARTICLE

Upside risk, consumption value, and market returns to food safety

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Abstract

We investigate the effect of a modest food safety premium on semisubsistence farmers' investment in a food safety technology. We demonstrate theoretically that in the face of production uncertainty, a market incentive below the marginal production cost of achieving the safety standard can increase food safety investment among farmers motivated by private health returns. We test this prediction through a randomized controlled trial in Kenya through which members of existing farmer groups were offered an opportunity to purchase a food safety input, and half were offered a 5% market premium for produce that met the associated regulatory standard. Access to the premium more than doubled investment in the food safety technology. In line with the model's prediction, most premium-induced adoption was by farmers motivated by a combination of health and financial rewards.

KEYWORDS

food safety, risk, smallholder farmers, technology adoption

JEL CLASSIFICATION

I12, L15, Q12, Q18

1 | INTRODUCTION

Agricultural markets in low-income countries are often characterized by an equilibrium of low quality and low prices. Limited demand for quality, small scale of production and trade, and long supply chains, contribute to weak market incentives for farmers to invest in the quality of their output. This situation limits the income potential of farming and contributes to the considerable health risk posed by food safety hazards originating at production. Increasing attention to food safety among public regulatory bodies in these settings means that some processors are willing to pay a modest quality premium for raw ingredients that meet regulatory standards.[i] In this paper, we investigate the effect of a quality premium reflecting local mass-market demand in the context of production uncertainty among semisubsistence farmers.

Although several studies have shown that access to an export or niche local market offering a large quality premium can improve compliance with food safety standards and increase farm profits (Bold et al., 2022; Deutschmann et al., 2021; Magnan et al., 2021), the potential for market incentives to improve food safety in mass markets of low-income countries is not well understood. We demonstrate, theoretically and through analysis of a cluster-randomized trial, that if small-scale farmers consume a portion of what they grow, and derive utility from household consumption of high-quality food, this consumption motivation can amplify the impact of small incentives on agricultural technology adoption.

Our theoretical model shows that a quality premium below the cost to farmers of meeting the standard required to earn that premium can nonetheless increase investment in a quality-enhancing technology under two conditions. First, farmers must derive a consumption value on the target quality, and second, the quality-enhancing technology must be applied before agricultural yield is realized. Farmers would prefer to invest only in the quality of food consumed by the household, but due to yield uncertainty, the level of investment required to achieve this amount of high-quality output is uncertain. In expectation, farmers derive a consumption benefit from investing in the quality of any food that has a positive probability of being consumed by the household. A market premium, even if below the cost of attaining the required quality standard, can complement this expected consumption benefit so that the total expected benefit to the farmer exceeds the marginal cost of the investment. This implies that market incentives that may appear too small to impact farmers' behavior from a purely commercial perspective could nonetheless stimulate agricultural quality upgrading. We test and find support for the model's predictions through a randomized trial involving 152 maize producer groups in Kenya.

We make two primary contributions to the literature. First, we develop a novel theoretical model showing how consumption utility and monetary incentives interact to influence the adoption of an agricultural technology. The interplay of these incentives is critical to the supply of food safety in settings where the market premium for food safety is low due imperfect observability and the high cost of hazard detection (Fafchamps et al., 2008). The model also applies to any other quality attribute from which producer-consumers derive direct utility and which do, or could potentially, fetch a premium price. Examples include biofortified crops (Birol et al., 2015) and varieties with preferred taste, processing, or storage properties (Smale et al., 2001).

Much of the prior empirical work on the adoption of quality-enhancing technologies has focused on relatively high-value outputs such as milk and vegetable crops produced primarily for sale (Bernard et al., 2017; Saenger et al., 2013; Treurniet, 2021b), to which consumption preferences are not as relevant. Three recent studies have investigated the adoption of food safety practices for produce that constitutes a significant share of producers' dietary intake. Hoffmann and Jones (2021) find that farmers who produce solely for home consumption use better food safety practices at baseline and are more likely to adopt a new technology in the absence of market incentives, and that these incentives only affect the behavior of those who produce for the market. Deutschmann et al. (2021) find that farmers who consume at least some of their crop are more likely to take up a contract offering a food safety premium, bundled with access to training and credit, whereas Magnan et al. (2021) do not detect significant heterogeneity in the impact of a market incentive on this dimension. No papers of which we are aware develop a formal theory addressing the interactions between consumption and financial motivators as drivers of adoption.

The model relates to the role of production risk—due for example to variation in rainfall and pest attacks—in agricultural technology adoption. Although a vast literature on how downside yield risk affects adoption of agricultural technologies, including Just and Pope's (1978) seminal theoretical contribution, followed by empirical treatments by Rosenzweig and Binswanger (1993), Dercon and Christiaensen (2011), and Emerick et al. (2016), upside yield risk has received far less attention. In the context of a quality-enhancing input that is applied before the realization of yield and increases the consumption value of produce to the famer, we show theoretically that harnessing upside yield risk through a market incentive for quality can be an important driver of adoption and present experimental evidence consistent with this mechanism.

Our second contribution is to provide experimental evidence on how a food safety premium of the magnitude observed in processed maize flour in Kenya could influence on-farm investment in this attribute were it to be transmitted to producers.

The quality dimension addressed through the randomized trial is contamination with aflatoxin, a toxic fungal byproduct (mycotoxin) that primarily affects maize and groundnut. Dietary exposure to aflatoxin accounts for a large share of the liver cancer burden in sub-Saharan Africa, Southeast Asia, and China (Liu & Wu, 2010), and evidence is emerging that the toxin plays a role in stunting (Gong et al., 2004; Hoffmann, Jones, & Leroy, 2018; Turner et al., 2007). Aflatoxin contamination is generally highest in rainfed agricultural systems that are also characterized by significant yield risk (Chauhan et al., 2008).

Aflatoxin risk in maize can be greatly reduced through the application of a biocontrol product to fields while the crop is still growing. This technology, which harnesses atoxigenic strains of the same fungus that produces aflatoxin, was adapted for use in maize and groundnut in Africa under the name Aflasafe. Previous experimental studies in which Aflasafe was applied by researchers have shown that use of this product reduces aflatoxin in maize by upwards of 95% in years when contamination is exceptionally high and by 85% on average (Atehnkeng et al., 2014; Bandyopadhyay et al., 2019; Senghor et al., 2020). As a fixed amount of the biocontrol product is applied to fields early in the growing cycle, farmers stand to harvest more safe grain for a given cultivated area if subsequent growing conditions are good and less if conditions are poor. Although field trials of Aflasafe have been conducted in eastern Kenya, the product was not yet commercially marketed at the time of the present study, and hence farmers' awareness and adoption of this technology were close to zero.[ii]

Members of 152 maize producer groups were invited to attend informational meetings held shortly before the time of maize planting. During these meetings, health problems associated with aflatoxin exposure were described, and the biocontrol technology was introduced. All groups were told that they would have an opportunity to purchase Aflasafe, and half were told that they would be linked to a buyer that would purchase aflatoxin-safe maize at a fixed premium equal to approximately 5% above the market price of maize at harvest. A few weeks later, immediately before the point in the growing cycle at which aflatoxin biocontrol should be applied, all of the groups were visited again and offered an opportunity to purchase Aflasafe.

We find that despite the low profitability of the technology for most farmers, the market premium increased the proportion of farmers who adopt by over 75% and more than doubled the mean amount of the product purchased. The vast majority of farmers who purchased biocontrol—including those offered the market incentive—indicated that they did so to ensure safe food for their families. These results are consistent with our model in which farmers value safe food for their own consumption but fail to adopt or to fully adopt due to uncertainty about whether they will capture the full value of this investment. Introduction of a modest quality premium allows farmers to capture additional value from the quality investment in case their yield exceeds what is required for home consumption, thus increasing both adoption and intensity of use. Spillover effects on adoption in neighboring villages are substantial and appear to arise primarily through the stimulation of demand for safer food for own consumption.

We begin by presenting a simple model of the food safety investment decision faced by a subsistence farmer in the context of production risk in Section 2. In Section 3, we describe the food safety hazard targeted, market context, technology offered, and study population. Section 4 describes the study design and data, and Section 5 outlines the empirical strategy. Results are presented in Section 6, and Section 7 offers concluding remarks.

2 | MODEL

In this section, we formally derive conditions under which a price premium increases adoption of a food safety technology among subsistence farmers whose production process is stochastic. We start by defining farmers' utility as a function of investment in the technology. Farmers vary in the additional value they derive from consumption of safe food: The high (low) type has a high (low) valuation for food safety. We then derive solutions to each type's utility maximization problem when output meeting a food safety standard is rewarded by a market premium that exceeds the marginal cost of meeting that standard per expected unit of safe output and one that is below this cost.

2.1 | Set-up

Assume that farmers maximize the following utility function:

$$\max E[U] = E[V] + E[Y], \tag{1}$$

Subject to the budget constraint:

$$\mathrm{cI} + \mathrm{Y} = \mathrm{R}, \tag{2}$$

Where V is the total value of home consumption, Y is consumption of the composite good,[iii] $c > 0$ denotes the total cost of applying a food safety technology to the entire cultivated area,[iv] $I \in [0,1]$ is the proportion of land to which the technology is applied—the choice variable,[v] and R is total revenue received for farm produce delivered to the market. The total harvested amount is stochastic and uniformly distributed $q \sim U(q_L, q_H)$, so that the expected harvest equals $\mu_q = (q_L + q_H)/2$, and is not affected by the application of food safety technology. The food safety technology is applied before the harvested amount is realized, and we assume that investment in the technology is not affected by credit constraints.

We substitute (2) in (1) to obtain the following, simplified maximization problem:

$$\max E[U] = E[V] + E[R] - cI, \tag{3}$$

We further impose the following assumptions: (i) use of the food safety technology results in safe produce with certainty, so that $s = I$, where s is the proportion of food produced that is safe,[vi] (ii) due to a variable transaction cost of selling maize, home consumption is the minimum of the amount harvested and a fixed value at which the household's demand for produce is satiated: $q_{home} = \min\{q, \widetilde{q_{home}}\}$,[vii] (iii) $\widetilde{q_{home}} \le q_H$ such that the farmer faces the upside risk of producing more than is required to satisfy subsistence needs, and (iv) the remainder $q_{market} = q - q_{home}$ is sold. For ease of exposition, we assume for the formal derivation that the food safety technology is perfectly divisible and that there is no fixed cost of adoption. In the graphical analysis that follows, we describe the implications of relaxing these assumptions.

Safe food produced will either be consumed at home or delivered to the market:

$$\mathrm{s_{home} q_{home}} + \mathrm{s_{market} q_{market}} = \mathrm{Iq}, \tag{4}$$

where $s_{home} \in [0,1]$ is the proportion of produce consumed by the household that is safe, and $s_{market} \in [0,1]$ is the proportion of produce delivered to the market that is safe. The farmer first chooses the level of investment I, and then chooses s_{home} and s_{market} after the realization of q.

The total value of home consumption equals:

$$\mathrm{V} = (\alpha + \beta_{\mathrm{i}} \mathrm{s}_{\mathrm{home}}) \cdot \mathrm{q}_{\mathrm{home}}, \tag{5}$$

where α is the value of consuming food of the quality produced by the farmer in the absence of any food safety investment, and β_i is the value premium for consuming safe food.

Farmers vary in the value they derive from consumption of safe food; for the sake of tractability, we define food safety preferences as either low (L) or high (H).

$$\beta_{\mathrm{i}} \in \{\beta_{\mathrm{L}}, \beta_{\mathrm{H}}\}, \tag{6}$$

where we assume that:

$$\beta_{\mathrm{L}} < \frac{\mathrm{c}}{\mu_{\mathrm{q}}} < \beta_{\mathrm{H}} < \widetilde{\beta} \equiv \frac{\mathrm{c}}{\left.\frac{\partial \mathrm{E}\left[\mathrm{s}_{\mathrm{home}}\mathrm{q}_{\mathrm{home}}\right]}{\partial \mathrm{I}}\right|_{\mathrm{I}=1}}, \tag{7}$$

The first inequality ensures that the low type will not adopt the technology in the absence of a premium because the marginal cost per expected unit of safe output at $I = 0$ is more than the marginal utility benefit of consuming the resulting safe maize. The second ensures that the high type will adopt even in absence of a premium price for safe output. The third inequality implies that the high type's motivation to produce safe food for home consumption is by itself insufficient for full adoption, so that some room is left for market incentives to increase the intensity of adoption. If the last inequality is not satisfied, then as long as the high type does not treat his full land, marginal utility benefit of resulting safe home consumption will outweigh the marginal cost of obtaining it.

The total revenue obtained from sale of produce equals:

$$\mathrm{R} = (\gamma + \delta \mathrm{s}_{\mathrm{market}}) \mathrm{q}_{\mathrm{market}}, \tag{8}$$

where γ is the standard commodity price, and δ is the market quality premium.[viii]

Incorporating Equations (5) and (8) into the farmers' utility maximization problem:

$$\max_{I, s_{home}, s_{market}} E[U] = \alpha E\left[q_{home}\right] + \beta_i E\left[s_{home} q_{home}\right] + \gamma E\left[q_{market}\right] + \delta E\left[s_{market} q_{market}\right] - cI, \tag{9}$$

subject to (4), and $s_{home}, s_{market}, I \in [0, 1]$.

2.2 | Solution

Case 1: No market premium

In the absence of a market premium for food safety, $\delta = 0$, so that the only incentive to invest in food safety is due to the farmer's own preference for safe food, represented in the model by the parameter β_i. The farmer will select her safe produce for home consumption and deliver the remainder to the market, so that:

$$s_{home} q_{home} = \min\left\{Iq, q_{home}\right\} = \min\left\{Iq, \widetilde{q_{home}}\right\} = \begin{cases} Iq & if\ q \leq \dfrac{\widetilde{q_{home}}}{I} \\ \widetilde{q_{home}} & if\ q > \dfrac{\widetilde{q_{home}}}{I} \end{cases}, \tag{10}$$

which in expectation equals:

$$E\left[s_{\mathrm{home}}q_{\mathrm{home}}\right]=\begin{cases} I\mu_q & \text{if } I\le \dfrac{\widetilde{q_{\mathrm{home}}}}{q_H} \\ f(I) & \text{if } \dfrac{\widetilde{q_{\mathrm{home}}}}{q_H}<I\le \dfrac{\widetilde{q_{\mathrm{home}}}}{q_L}, \\ \widetilde{q_{\mathrm{home}}} & \text{if } I>\dfrac{\widetilde{q_{\mathrm{home}}}}{q_L} \end{cases} \tag{11}$$

where:

$$f(I)=\int_{q_L}^{\widetilde{q_{\mathrm{home}}}/I} Iq\frac{1}{q_H-q_L}dq+\int_{\widetilde{q_{\mathrm{home}}}/I}^{q_H}\widetilde{q_{\mathrm{home}}}\frac{1}{q_H-q_L}dq, \tag{12}$$

is the expected amount of safe home consumption if the level of investment is such that there is some chance that the amount of safe harvest is insufficient to satisfy the subsistence needs (in which case the full safe harvest Iq will be consumed at home) and some chance that the amount of safe harvest is sufficient to satisfy subsistence needs (in which case the full amount of home consumption $\widetilde{q_{home}}$ will be safe).

Equation (11) is differentiable and monotonically increasing in I, and its first derivative with respect to I equals:

$$\frac{\partial E\left[s_{\mathrm{home}}q_{\mathrm{home}}\right]}{\partial I}=\begin{cases} \mu_q & \text{if } I\le \dfrac{\widetilde{q_{\mathrm{home}}}}{q_H} \\ \dfrac{1}{2}\dfrac{\left(\widetilde{q_{\mathrm{home}}}/I-q_L\right)\left(\widetilde{q_{\mathrm{home}}}/I+q_L\right)}{q_H-q_L} & \text{if } \dfrac{\widetilde{q_{\mathrm{home}}}}{q_H}<I\le \dfrac{\widetilde{q_{\mathrm{home}}}}{q_L}, \\ 0 & \text{if } I>\dfrac{\widetilde{q_{\mathrm{home}}}}{q_L} \end{cases} \tag{13}$$

which is continuous and monotonically decreasing in I. Mathematical details are included in Section 1 of the online supplementary Appendix S1.

Intuitively, Equation (11) says that when investment in food safety is so low that there is not sufficient safe produce to satisfy home consumption needs even in the case of the best possible harvest, all safe food is consumed by the household. Equation (13) shows that beyond this level of investment, the expected quantity of safe home consumption is increasing with investment in food safety, but at a decreasing rate, because the greater the share of land to which the technology is applied, the higher the chance of producing more than is needed for household consumption. Eventually (if $\widetilde{q_{home}}<q_L$) investment in the food safety technology reaches a point at which there will be sufficient safe produce for home consumption even when the worst possible harvest is realized.

For farmers who place a low value, β_L, on the safety of home consumption, we have from Equations (13) and (7) that:

$$\beta_L\frac{\partial E\left[s_{\mathrm{home}}q_{\mathrm{home}}\right]}{\partial I}\le\beta_L\mu_q<c, \tag{14}$$

which implies that the marginal benefits of treating land with the food safety technology are strictly smaller than the marginal cost of treating land. These farmers will not invest in food safety in the absence of a price premium.

For farmers who place a high value, β_H, on the safety of home consumption, we have $\beta_H \mu_q > c > 0$ and:

$$\beta_{\mathrm{H}} \frac{\partial \mathrm{E}\left[\mathrm{s}_{\mathrm{home}} \mathrm{q}_{\mathrm{home}}\right]}{\partial \mathrm{I}}\bigg|_{\mathrm{I}=1} < \mathrm{c}, \tag{15}$$

so that the optimal investment I^* is uniquely defined by:

$$\beta_{\mathrm{H}} \frac{\partial \mathrm{E}\left[\mathrm{s}_{\mathrm{home}} \mathrm{q}_{\mathrm{home}}\right]}{\partial \mathrm{I}}\bigg|_{\mathrm{I}=\mathrm{I}^*} = \mathrm{c}, \tag{16}$$

Intuitively, farmers with a high value of safe home consumption invest in food safety until the probability that additional safe harvest will be consumed at home becomes too low to justify the cost of investment.

Case 2: Premium above cost of compliance

Now consider the case of a price premium greater than the marginal cost (per expected unit of safe output $\delta > c/\mu_q$) of complying with the safety standard required to obtain the premium. Farmers with a low valuation for safe home consumption β_L will now adopt the food safety technology. However, these farmers will not apply the food safety technology to their entire cultivated area due to the low utility benefit they derive from consuming safe produce. Because $\beta_L < c/\mu_q < \delta$, they will first consume untreated maize at home and will prioritize safe maize for sale at the premium price.[ix] Farmers with a high valuation for safe home consumption, β_H, will increase adoption and apply the food safety technology to their entire cultivated land area, so that all their produce will be safe. This leads to Proposition 1:

> **Proposition 1.** A price premium above the marginal cost of achieving compliance with the required standard per expected unit of safe output increases adoption at both the extensive margin (whether the technology is used at all) and the intensive margin (how much of the technology is used by adopters).

Case 3: Premium below cost of compliance

Because $\beta_H > c/\mu_q > \delta$, farmers with high valuation of safety of home consumption β_H will still select their safe produce for home consumption and deliver the remainder to the market, so that Equations (10) to (13) still hold, and:

$$s_{market} q_{market} = \max\left\{0, Iq - \widetilde{q_{home}}\right\} = \begin{cases} 0 & if\ q \leq \dfrac{\widetilde{q_{home}}}{I} \\ Iq - \widetilde{q_{home}} & if\ q > \dfrac{\widetilde{q_{home}}}{I} \end{cases}, \tag{17}$$

which in expectation equals:

$$\mathrm{E}\left[\mathrm{s_{market}q_{market}}\right]=\begin{cases}0 & \text{if } \mathrm{I}\le\frac{\widetilde{\mathrm{q_{home}}}}{\mathrm{q_H}}\\ \mathrm{g(I)} & \text{if } \frac{\widetilde{\mathrm{q_{home}}}}{\mathrm{q_H}}<\mathrm{I}\le\frac{\widetilde{\mathrm{q_{home}}}}{\mathrm{q_L}},\\ \mathrm{I}\mu_\mathrm{q}-\widetilde{\mathrm{q_{home}}} & \text{if } \mathrm{I}>\frac{\widetilde{\mathrm{q_{home}}}}{\mathrm{q_L}}\end{cases} \tag{18}$$

where:

$$\mathrm{g(I)}=\int_{\widetilde{\mathrm{q_{home}}}/\mathrm{I}}^{\mathrm{q_H}}\left(\mathrm{Iq}-\widetilde{\mathrm{q_{home}}}\right)\frac{1}{\mathrm{q_H}-\mathrm{q_L}}\mathrm{dq}, \tag{19}$$

Equation (18) is differentiable and monotonically increasing in in I, and its first derivative with respect to I equals:

$$\frac{\partial\mathrm{E}\left[\mathrm{s_{market}q_{market}}\right]}{\partial\mathrm{I}}=\begin{cases}0 & \text{if } \mathrm{I}\le\frac{\widetilde{\mathrm{q_{home}}}}{\mathrm{q_H}}\\ \frac{1}{2}\frac{\left(\mathrm{q_H}-\widetilde{\mathrm{q_{home}}}/\mathrm{I}\right)\left(\mathrm{q_H}+\widetilde{\mathrm{q_{home}}}/\mathrm{I}\right)}{\mathrm{q_H}-\mathrm{q_L}} & \text{if } \frac{\widetilde{\mathrm{q_{home}}}}{\mathrm{q_H}}<\mathrm{I}\le\frac{\widetilde{\mathrm{q_{home}}}}{\mathrm{q_L}},\\ \mu_\mathrm{q} & \text{if } \mathrm{I}>\frac{\widetilde{\mathrm{q_{home}}}}{\mathrm{q_L}}\end{cases} \tag{20}$$

and is continuous and monotonically increasing in I, where again the last case can only occur if $\widetilde{q_{home}}<q_L$.

For farmers with a high valuation of safe home consumption β_H, we have $\beta_H\mu_q>c>0$, so that the optimal investment I^{**} is uniquely defined by:

$$\beta_\mathrm{H}\frac{\partial\mathrm{E}\left[\mathrm{s_{home}q_{home}}\right]}{\partial\mathrm{I}}\bigg|_{\mathrm{I}=\mathrm{I}^{**}}+\delta\frac{\partial\mathrm{E}\left[\mathrm{s_{market}q_{market}}\right]}{\partial\mathrm{I}}\bigg|_{\mathrm{I}=\mathrm{I}^{**}}=\mathrm{c}, \tag{21}$$

which has a solution for $I\le1$, or otherwise $I=1>I^*$.

Equation (21) can be reduced to:

$$(\beta_\mathrm{H}-\delta)\frac{\partial\mathrm{E}\left[\mathrm{s_{home}q_{home}}\right]}{\partial\mathrm{I}}\bigg|_{\mathrm{I}=\mathrm{I}^{**}}+\delta\mu_\mathrm{q}=\mathrm{c}, \tag{22}$$

The LHS of Equation (22) is decreasing in I^{**} and, by Equations (16) and (21), this exceeds c for $I^{**}\le I^*$. We therefore conclude that $I^{**}>I^*$, meaning that a non-zero price premium below the marginal cost of adoption per expected unit of safe output has a positive effect at the intensive margin of investment due to increased intensity of adoption by high types. This leads to Proposition 2a:

Proposition 2a. A positive price premium below the expected marginal cost of compliance with the required standard per expected unit of safe output increases adoption of the food safety technology at the intensive margin.

Intuitively, if production of safe food were to exceed household subsistence needs (e.g., due to favorable weather conditions), a portion of the value of the food safety investment would be lost if no market reward for quality were available. The market premium allows farmers with a high valuation of safe home consumption to capture the additional value of that investment in the face of a positive production shock.

2.3 | Graphical representation

Figure 1 depicts how the introduction of a market premium affects the optimal food safety investment when the premium is below the cost of compliance with the standard required to obtain the premium payment. The solid gray line represents marginal expected utility from home consumption. Initially this is higher than the marginal cost of food safety technology per expected unit of safe output, but it eventually decreases as the probability increases that some of the resulting safe maize will exceed household needs and will be sold to the market. The household adopts until the marginal expected value of home consumption equals the cost of food safety technology, so that the optimal food safety investment equals I^*. However, a modest market premium can offset part of the decrease in marginal expected utility from home consumption. The marginal expected utility with a modest market premium thus decreases less than the marginal expected utility without a market premium, so that the optimal food safety technology equals I^{**}.

As illustrated by Figure 1, production uncertainty drives this result. If $q_H = q_L = \overline{q}$, the marginal expected utility of investment in food safety would be a step function, dropping from $\beta\mu_q$ to $\delta\mu_q$ at $q_{home}/\overline{q}$, and a premium below the marginal cost of achieving the standard per expected unit of safe output would have no impact on the farmer's adoption decision.

2.4 | Model extensions

We use Figure 2 to discuss two model extensions: fixed costs and indivisible units of technology. In both cases, a price premium below the marginal cost of compliance with the required standard per

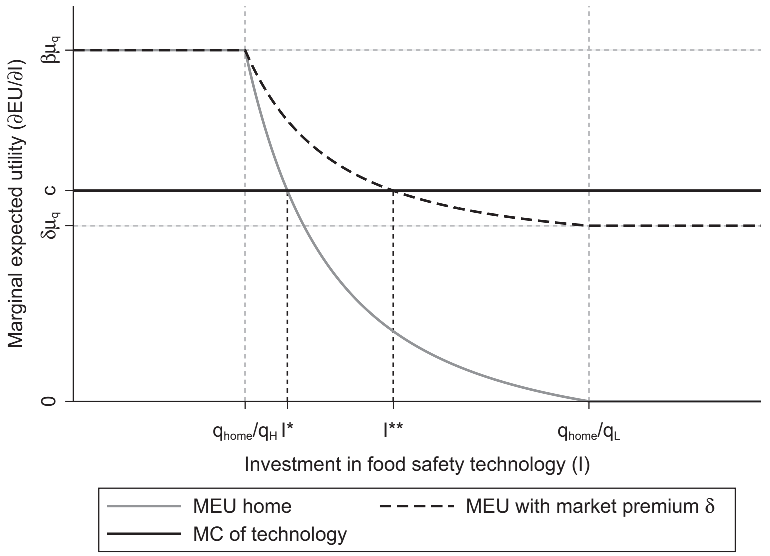

FIGURE 1 Model representation

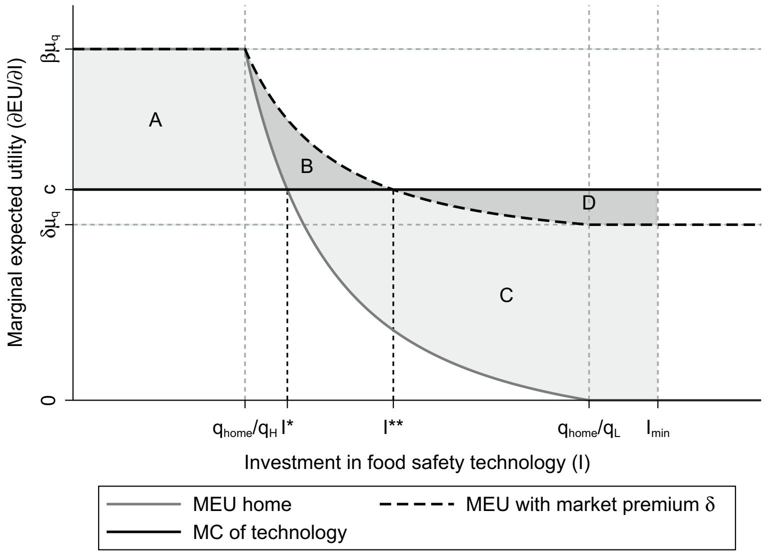

FIGURE 2 Model extensions

expected unit of safe output also has the potential to increase investment in food safety technology at the extensive margin.

First, consider a fixed cost of food safety investment of C_0. Then, without a market premium, the farmer will not invest in the food safety technology if her net utility gains of adopting (area A) are smaller than the fixed costs. However, the extra net utility gains from the market premium (area B) can cause the farmer's total utility gains to exceed the fixed cost, so that she will also adopt at the extensive margin.

Second, suppose that the farmer faces a choice between nonadoption and some minimum level of adoption, I_{min}. Then, without a market premium, adoption would cause the farmer to gain Area A, but lose Areas C and D. With a market premium, her gains increase by Area B, and losses decrease by Area C. Thus, with the introduction of a market premium, the gains are more likely to exceed the cost of adoption, potentially generating an increase in adoption at the extensive margin.

We therefore arrive at Proposition 2b:

> **Proposition 2b.** A positive price premium below the marginal cost of compliance with the required standard per expected unit of safe output can increase adoption of the food safety technology at the intensive and extensive margin if there exists a fixed cost of adoption or if the technology is not perfectly divisible.

In these extensions, production uncertainty, although no longer essential to the impact of a premium below *c*, strengthens its effect by increasing the farmer's expected utility of investing beyond $I = q_{home}/q_H$. This leads us to Proposition 3:

> **Proposition 3.** The effect of a price premium below the expected marginal cost of compliance with the required standard per expected unit of safe output is increasing in production uncertainty.

3 | STUDY CONTEXT

In this section, we first describe the problem of aflatoxin contamination in the study site of eastern Kenya and provide background on the market for safe maize in this setting. We then describe the population of farmers recruited into the experiment.

3.1 | Aflatoxin, biocontrol, and the market for safe maize in Kenya

Dozens of cases of acute aflatoxin poisoning have been linked to the consumption of maize produced and stored by households in eastern Kenya, the setting of our study (Daniel et al., 2011). Likely because of these poisoning events, which have been covered extensively in Kenyan media, awareness of aflatoxin is high in the study region (Hoffmann et al., 2021).

The aflatoxin biocontrol product Aflasafe was approved by the Kenyan government for general use in June 2015, and domestic manufacturing began in 2017. The cost to produce 1 kg of Aflasafe at scale ranges between US $0.7 and $1.2 depending on currency exchange rates and the price of materials (Bandyopadhyay et al., 2016). Although the current price of Aflasafe in Kenya, including distribution costs and retail margins, is approximately US $1.80 per kg due to low production and sales volumes, we offered Aflasafe to farmers in the study at a price of 80 KSH (US $0.78) per kg; this lies within the range of production costs and takes into account the Government of Kenya's expressed support for a partial subsidy targeted to smallholders. Treating one acre of land requires 4 kg of Aflasafe.

The informal markets to which most smallholder maize farmers in Kenya sell do not reward unobservable quality (Hoffmann et al., 2021). However, a growing number of maize millers test for aflatoxin at purchase and typically offer a premium above the spot market price of maize in the informal market and sell their maize at a higher price point (Andae, 2019; Hoffmann & Moser, 2017). Millers approached as potential buyers of maize produced by study farmers were either located prohibitively far from the study site or unwilling to pay a significant quality premium. We estimated, based on the previously reported aflatoxin-price gradient (Hoffmann & Moser, 2017) and discussions with millers, that if a premium brand were to be introduced by a miller within this part of eastern Kenya, it would be feasible to pass on a quality payment of 100 KSH per 90 KG bag (approximately $1 US, and 5% of the price of a bag of maize) to farmers, after accounting for additional testing and procurement costs.

Because the cost of testing for aflatoxin is high relative to the value of produce sold by the typical smallholder farmer, the output of such farmers must be aggregated prior to testing. This can be done through producer groups, which are common in the study region and throughout sub-Saharan Africa. Producer groups may be formed by NGOs or other external actors as a platform for providing agricultural training and extension or established by farmers to aggregate their demand for inputs or supply of produce in order to reduce transaction costs or increase bargaining power.

3.2 | Study population and identification of producer groups

The study population consisted of maize farmers who were members of existing producer groups in Meru, Embu, and Tharaka Nithi counties, Kenya, an area known for high levels of aflatoxin contamination. The mean aflatoxin level in stored maize sampled from control villages for a separate trial in the same region in 2015, when aflatoxin contamination was considered moderate, was 18.5 ppb, 85% higher than the maximum allowable level in Kenya (Pretari et al., 2019). In 2010, recognized as an aflatoxin outbreak year, the mean level of contamination was 47 ppb, 4.7 times the legal limit (Mutiga et al., 2014). In both years, results from the field trials cited above indicate that treating fields with Aflasafe would have brought the average level of contamination into the legal range.[x]

A list of 224 producer groups in the study area was acquired through the Cereal Growers' Association (CGA), a national member-based farmer organization, and the Ministries of Agriculture in each of the three study counties. From April to August 2017, these groups were visited and lists of their members were obtained. From these 224 groups, we selected 152 groups into the experiment.[xi]

4 | STUDY DESIGN

This section describes the experimental treatments. Scripts used during meetings with farmers are provided in the supplementary online materials.

4.1 | Farmer training and sale of biocontrol product

All 152 producer groups in the experiment were given information on aflatoxin as well as the benefits of aflatoxin biocontrol and instructions on its use. This was done through two rounds of training, each delivered during a half-day meeting to which all group members were invited. The first round of training took place in September–October 2017, planting time in the study area. During these meetings, group members were informed that they could only purchase the biocontrol product through the project as it was not yet commercially available in the study area.

A second round of training was conducted in November and early December, a few weeks after planting and just before the time at which Aflasafe should be applied. During these meetings, which were identical across the market linkage treatment and control groups, a demonstration of Aflasafe application was conducted on the farm of one member of each group. At the end of these meetings, those present were given an opportunity to purchase the product, which was offered in packages of 4 kg, a quantity sufficient to treat one acre of land. Farmers who wished to purchase less than 4 kg were asked to pair up with another group member and share a single package.[xii] Both rounds of training were conducted by extension agents employed by the CGA, who had been trained on the use of Aflasafe by the International Institute of Tropical Agriculture (IITA), which also supplied the product.

Seasonal cash constraints, combined with lack of access to credit, may constitute a significant barrier to adoption of agricultural technologies in this setting. To partially address this barrier, farmers who wished to purchase Aflasafe but had not mobilized sufficient cash to do so by the second training were given another chance to do so at a subsequent sales visit that was scheduled based on demand approximately 1 week later.

4.2 | Experimental design

Half of the villages in which participating producer groups were based were randomly assigned to receive a premium price for safe maize (output market linkage treatment).[xiii] The output market linkage treatment was cross cut with a bundled insurance treatment, in which Aflasafe could only be purchased together with rainfall index insurance. Farmers not assigned to the bundled insurance treatment who purchased Aflasafe were able to purchase the same insurance separately. This was an actuarially fair rainfall index insurance specifically designed to insure the investment in Aflasafe against weather related shocks. The insurance treatment is not analyzed in this paper, but as described in Hoffmann, Kariuki, Pieters, and Treurniet (2018), most farmers that had the option bought insurance so that the two insurance arms were similar in practice and bundling insurance with Aflasafe did not affect Aflasafe adoption.

During the initial round of training, groups in villages assigned to the output market linkage treatment were promised a bonus of 100 KSH per 90-kg bag of maize found to conform to the regulatory aflatoxin standard. The bonus was to be paid shortly after harvest. Members who had purchased Aflasafe and wanted to sell their maize through the project would aggregate their maize at a central place to be identified by the group members. A rapid qualitative aflatoxin test would be conducted on the aggregated maize to check if the maize had aflatoxin levels higher than the East African limit (10 ppb). Farmers were informed that any aggregated maize that contained levels higher than 10 ppb would not qualify for the bonus. They were advised to record the number of members who purchased Aflasafe in their group and the amount purchased by each member, and to ensure that only treated maize was aggregated for testing, to avoid the inclusion of contaminated maize that lead to the entire group's maize testing above the standard. Aggregation of maize and payment of the bonus took place in March–April 2018, at the same time as endline data collection and shortly after completion of the maize harvest.

4.3 | Data

A short survey of all 224 producer groups on the initial list was conducted during meetings with these groups in April–August 2017 (henceforth referred to as census meetings) for the purposes of sample selection, stratification, and balance checks. Data on each group's geographical location, as well as their members' familiarity with weather insurance, awareness of aflatoxin, use of agricultural inputs, and levels of maize production and marketing were collected. Lists of the groups' members, and data on who among these were present during the census meeting, were also obtained.

After selecting 152 groups into the study as described above, baseline survey data were collected in September–October 2017. Both household and group-level surveys were administered immediately prior to the first training meeting, at the site of the meeting. Six farmers per group were randomly selected to be interviewed from among those present during the census meeting.[xiv] Of the 3605 group members listed during the census, 892 were interviewed at baseline.[xv] The baseline group-level questionnaire was administered to one or more of each group's leaders.

Table 1 provides descriptive statistics from the baseline household survey. The majority of respondents were female. The average respondent has 1.68 acres under maize, and 47% had sold maize from the previous harvest. Most respondents had heard of aflatoxin, 79% were able to describe it accurately, and the same proportion were able to identify at least one associated health issue. Stomach pain was the most frequently mentioned health problem (60% of respondents), whereas cancer and child stunting were mentioned by 17% and 1% of the respondents, respectively. Most farmers were able to list at least one aflatoxin prevention measure, such as drying maize well before storage, which most farmers also do. Finally, 10% of the farmers had heard of Aflasafe, and 2% reported ever having used the product.

Administrative data on farmers' purchases of Aflasafe were collected during sales visits in November and early December 2017. For each farmer who purchased the product (including those who purchased less than 4 kg), name, gender, land area under maize, and the amount of Aflasafe purchased were recorded. These data were used to construct the main outcome variables: adoption (equal to 1 if the farmer purchased any Aflasafe and 0 if the farmer did not), and adoption intensity (a continuous variable indicating the amount purchased).

A follow-up survey with the same respondents interviewed at baseline was conducted in March–April 2018, after the completion of the maize harvest. Three of the baseline respondents could not be located, resulting in 889 observations at endline.[xvi] As the remainder of the paper makes use of different subsamples, we summarize these in Table 2.

4.4 | Randomization

The 152 producer groups that participated in the experiment were located in 124 villages. To avoid within-village spillover effects, assignment to the market linkage treatment was randomized at the

TABLE 1 Descriptive statistics

	N	Mean	SD
Respondent is female	892	0.776	0.417
Age of the farmer (completed years)	892	50.2	13.9
Years of education completed by head	892	7.16	4.01
Total land under maize this season (acre)	892	1.68	1.30
Maize marketing: whether sold any maize last season	892	0.474	0.500
Agricultural inputs & labor expenses main season previous year (USD)	892	106	113
Has heard of aflatoxin	892	0.885	0.320
Can describe what aflatoxin is	892	0.794	0.405
Knows of some health issue associated with maize consumption	892	0.787	0.410
Number of aflatoxin-induced health effects known	892	1.35	0.95
Number of aflatoxin prevention measures known	892	1.62	1.14
Number of aflatoxin prevention measures taken	892	1.61	1.20
Ever heard of Aflasafe	892	0.104	0.306
Ever used Aflasafe	892	0.019	0.137

TABLE 2 Sample sizes

	Market linkage			No market linkage			Total		
	Farmers	Groups	Villages	Farmers	Groups	Villages	Farmers	Groups	Villages
All farmers	1782	76	62	1823	76	62	3605	152	124
Surveyed at baseline	449	76	62	443	76	62	892	152	124
Not surveyed at baseline	1333	76	62	1380	76	62	2713	152	124

village level. Randomization was stratified by county and by rainfall index insurance treatment (described in sub-section 4.2 above). This design ensures that assignment to the bundled index insurance treatment is balanced across market linkage treatments. Table A1 in Section 4 of the online supplementary Appendix S1 provides statistics describing individual and household-level characteristics of baseline survey respondents, farmer group characteristics, and agroecological conditions, by market linkage treatment assignment.[xvii] The registered Pre-Analysis Plan contains a detailed description of the construction of the variables from survey data.[xviii] In addition, we show the mean rainfall index insurance trigger by treatment group. This variable was obtained from the insurance provider and reflects historic rainfall patterns at the location where the initial group census meeting was held. We find that the market linkage treatment groups are well-balanced on almost all observables. We do, however, find that farmers in the market linkage treatment were more likely to be present during the census meeting. Given that we test for balance on 27 variables, a significant difference on one of these is not unexpected and does not indicate structural differences across treatments. We control for farmers' presence during the census meeting in the analysis below, as well as for other observables.

4.5 | Farmer expectations at baseline

Table 3 shows summary statistics based on data collected at baseline, of the land farmers planned to plant with maize in the coming season and their expectations of the resulting harvest under normal, poor, and very good conditions. The amount of maize farmers expected to store for household consumption under a normal harvest, and the amount they expected to sell (assumed to be any maize not retained for household consumption) are also shown. Note that the mean expected harvest in a good season is 54% higher than that expected during normal years and nearly four times above that expected when the harvest is poor, indicating that farmers face considerable upside risk to food safety investments that are not rewarded in the market.

Based on the statistics presented in Tables 2 and 3, we can do a back-of-the-envelope calculation of the return on investment to Aflasafe using farmers' yield expectations. Suppose a mean (median) farmer in terms of land treats her entire maize plot with Aflasafe with the intention of selling this maize at a premium of 100 KSH ($0.97 US) per 90-kg bag above the market price. The expected premium payment earned in a normal season is $925/90 = 10.28$ bags × 100 KSH per bag = 1028 KSH (556 KSH for the median farmer), whereas the cost of Aflasafe (including rainfall insurance, which most farmers in our sample purchased) is 773 (460) KSH including the labor cost of application.[xix] With our price premium, the expected profit from investing in Aflasafe amounts to just 255 KSH (approximately $2.5 US) at the mean, and less than $1 US for the median farmer. Only 15% of farmers could expect to earn the equivalent of $10 US or more by investing in Aflasafe. Moreover, uncertainty about the effectiveness of the technology, the unobservable actions of fellow group members whose grain would be included in the tested lot, and the buyer's delivery of the incentive payment all reduce farmers' expected return on investment.

Propositions 2a and 2b of our model predict that giving farmers an opportunity to sell aflatoxin-safe maize at a premium price should increase farmers' investment in the safety of maize for household consumption in the face of an uncertain harvest, even if the premium is below the marginal cost of adoption per expected unit of safe output. In this case, treated maize would be used for household consumption first, but in the case of a bumper crop, the excess could be sold at a premium price. In this way, the introduction of a quality premium leverages upside agricultural production risk, introducing an additional incentive for the adoption of a technology with direct consumption value.

To illustrate, dividing the expected harvest and variables shown in Table 3 by land under maize to calculate yield, the mean (median) farmer would need to apply Aflasafe to 0.77 (0.50) acres to grow a sufficient volume of treated maize for her family's consumption from own produce in a normal year. The cost of Aflasafe for own consumption in this scenario, including application, is 354 (230) KSH. But in a bad year, treating the entire area under maize would be insufficient to ensure this much treated maize for 93% of farmers, implying that the mean area to which Aflasafe would be applied would be 1.30 acres, and the median 1 acre (equal to the median area under maize). Although a farmer may wish to feed her family safe maize, without access to a premium market for safe maize, she might be hesitant to spend this much on Aflasafe and risk wasting roughly half of her investment if the harvest turns out to be normal (and even more in case of an exceptionally good harvest). With access to a premium market, however, such a farmer could safely purchase enough Aflasafe to ensure sufficient treated maize for household consumption even in a bad year, knowing that if the treated land yields more maize than her household requires, she will reap a

TABLE 3 Maize production and sales expectations at baseline

	N	Mean	Median	*SD*
Expected harvest if season is normal (kg)	892	925	500	1150
Expected harvest if season is poor (kg)	892	367	180	609
Expected harvest if season is very good (kg)	891	1431	900	1524
Maize harvest main season previous year (kg)	892	444	180	757
Amount stored for family consumption, normal harvest (kg)	892	283	225	213
Calculated amount sold from a normal harvest (kg)	892	630	270	998

Note: Variables are winsorized at the 99th percentile.

premium price for this maize. In this way the market linkage treatment reduces the expected cost of precautionary investment in the treatment of maize for home consumption.

In addition, for a subset of farmers, adoption of Aflasafe is likely to be profitable under the price premium offered through the market linkage treatment. Assignment to the treatment group may induce these farmers to purchase the product based on a simple commercial calculation.

5 | EMPIRICAL STRATEGY

In this section, we describe the samples of farmers included in the primary analysis and robustness checks respectively, the regression models used to estimate treatment effects, and statistical power.

5.1 | Sample

Although new group members were allowed to buy Aflasafe, we restrict analysis to the farmers listed during the group census to avoid potential treatment effects on sample composition.[xx] The effect of being surveyed at baseline is the subject of a separate paper, which finds a positive impact of inclusion in the baseline survey sample on Aflasafe adoption (Treurniet, 2021a). Given this result, estimated treatment effects on the subsample of surveyed farmers are not externally valid. We therefore focus our primary analysis of the effect of the market linkage on technology adoption on farmers who were not surveyed at baseline.[xxi] To analyze mechanisms behind treatment effects, we use data from the sample of surveyed farmers.

To assess the robustness of our results with respect to the estimation sample, we also estimate treatment effects using the two prespecified samples: all farmers who were listed as members of participating producer groups during the initial census and those who participated in the baseline survey. Results for these samples, as well as results for the subsample of farmers that were not considered for baseline surveys and for the primary sample (non-surveyed farmers) but without reweighting, are presented in section 6 of the online supplementary Appendix S1.[xxii]

5.2 | Econometric model

To assess the effect of the premium market linkage treatment on farmers' adoption of Aflasafe, we estimate the following equation both with and without controls for baseline characteristics and proximity to groups assigned to the market linkage treatment[xxiii]:

$$\mathrm{Adoption}_{\mathrm{ijv}} = \kappa + \lambda \cdot \mathrm{Market}_{\mathrm{v}} + \left(\pi \cdot \mathrm{S}_{\mathrm{jv}}\right) + \left(\rho \cdot \mathrm{X}_{\mathrm{ij}}\right) + \varepsilon_{\mathrm{ijv}}, \tag{23}$$

where $Adoption_{ijv}$ represents either binary Aflasafe adoption or the amount of the product purchased by farmer i in farmer group j in village v, and $Market_v$ indicates whether the village was assigned to the market linkage treatment. The 1×3 vector S_{jv} is included to control for potential spillovers between villages and consists of three variables: the proportion of producer groups assigned to the market linkage treatment within a given radius of group j's meeting place, interacted with (a) treatment and (b) control status of village v, and a binary variable indicating the absence of any groups within this radius. X_{ij} is a vector of farmer and group-level baseline characteristics, as specified in the Pre-Analysis Plan and listed in Appendix Table A1.[xxiv] Following the prespecified approach to analysis of all study farmers (including those not surveyed at baseline), we use farmer group means of control variables measured through the individual baseline survey. ε_{ijv} is the error term. Standard errors are clustered at the village level. To test the impact of the market linkage treatment, we test whether $\lambda = 0$.

5.3 | Statistical power

Based on the observed intracluster correlation coefficients, sample size, and rate of Aflasafe adoption and mean purchase amount among the control group, the study was powered to detect an increase in (binary) Aflasafe adoption of 8 percentage points and an increase in the amount of the product purchased of 0.23 kg among the nonsurveyed group members that constitute the primary analysis sample.

6 | RESULTS

In this section, we first report summary statistics of outcome variables. We then go on to present estimated treatment effects of the market linkage treatment on Aflasafe adoption, controlling for differences at baseline as well as spillover effects. Finally, to shed light on the mechanisms behind these results, we present results on farmers' aflatoxin knowledge, beliefs about the efficacy of Aflasafe, and motivations for Aflasafe purchase.

Summary statistics and means tests presented in Table 4 show that adoption of Aflasafe was slightly higher among farmers residing in treatment villages but not significantly so. The amount of the product purchased per farmer was nearly twice as high in treatment villages, and this difference is highly significant at $p = 0.001$. A set of binary variables indicating surveyed farmers' stated reason for purchasing Aflasafe (set to zero for nonadopters), reveal systematic differences across experimental groups. Farmers in market linkage villages were 7.7 percentage points less likely to report the safety of food for household consumption as the only reason for adoption ($p = 0.07$), 1.3% more likely to report the premium price as the only reason for adoption ($p = 0.01$), and 4.2 percentage points more likely to report that both the premium price and safety of household food were factors in the decision to adopt.

In contrast, an index of aflatoxin knowledge at endline (constructed to have a mean of zero and standard deviation of one at baseline) was similar among Aflasafe adopters in the two treatment groups, as were beliefs about the probability that maize would become contaminated with aflatoxin despite treating the field with Aflasafe.

6.1 | Treatment effects

Table 5 reports estimates of the impact of the premium market linkage treatment on binary adoption of Aflasafe (Panel A) and the mean purchase amount, unconditional on adoption (Panel B). Odd-numbered columns show results without baseline controls, whereas even-numbered columns include controls. Columns 1 and 2 of the table present estimates without controls for cross-village spillovers. These estimates show no significant impact of the market linkage treatment on the extensive margin of adoption (the proportion of farmers adopting) but a positive impact on the total margin (amount of Aflasafe purchased).

Although the treatment was randomized at the village level to avoid intravillage spillovers across treatment groups, a substantial number of the villages included in the sample were close enough to one another that the risk of cross-village spillovers is a potential concern.[xxv] To address this, we add controls for the proportion of nearby groups assigned to the treatment group, interacted with indicators for the (group-level) assignment of each observation to the market linkage, and control group, respectively. We present three different specifications that control for spillover effects within a radius of 2 km (Columns

TABLE 4 Descriptive statistics for outcome variables

	Market linkage			No market linkage			Diff
	N	Mean	*SD*	*N*	Mean	*SD*	*p*
Adoption of Aflasafe							
Binary adoption	1333	0.163	0.389	1380	0.127	0.352	0.161
Quantity purchased (kg)	1333	0.566	1.660	1380	0.289	0.936	0.001
Reasons for purchasing Aflasafe							
Safety of own food only	449	0.261	0.439	443	0.332	0.471	0.071
Premium only	449	0.013	0.115	443	0.000	0.000	0.010
Safety of own food and premium	449	0.062	0.242	443	0.020	0.141	0.007
Aflatoxin knowledge and perceived chance of product failure							
Aflatoxin knowledge	448	0.455	0.566	441	0.489	0.525	0.340
Small or no chance of Aflasafe failure	420	0.852	0.355	408	0.865	0.342	0.660
No chance of Aflasafe failure	420	0.576	0.495	408	0.600	0.490	0.564

Note: For consistency with Table 5, adoption statistics are weighted by the inverse likelihood of inclusion in the sample; *p*-values are corrected for village level clustering.

3 and 4), 4 km (Columns 5 and 6), and 6 km (Columns 7 and 8), respectively. These models also include an indicator variable that is equal to one if no study groups are located within the specified radius.

The selection of the appropriate radius is based on a trade off. One that is too small risks excluding groups that are near enough to affect farmers' decisions. The effects of spillover effects from nearby groups will be large, but effects of more distant groups will be missed, potentially biasing downward the estimated treatment effect. On the other hand, as the radius expands, groups that are irrelevant to farmers' adoption decisions will be included, decreasing the magnitude of the estimated spillover effects and eventually rendering the spillover controls meaningless.

Including controls for the proportion of groups assigned to the market linkage treatment within a 2 or 4 km radius increases the estimated treatment effect size on both adoption and the amount of Aflasafe purchased. Effects of the market linkage treatment on both outcomes are significantly different from zero, whether or not baseline controls are included, and slightly larger when using the wider spillover radius. For control group farmers, the proportion of producer groups located within 2 km that were assigned to the market linkage treatment has a positive and significant effect on both binary adoption and the quantity of Aflasafe purchased. The coefficients on this term remain positive in models for both outcome variables when a 4 km radius is used but are smaller in magnitude and no longer significant. With a 6 km radius, the coefficient on the spillover term is close to zero for the binary adoption outcome, and the market linkage treatment effect is not statistically significant. For farmers in market linkage treatment groups, the treatment assignment of nearby groups does not have a significant effect on either Aflasafe adoption or the amount purchased in any of the specification presented.

As our primary goal is to characterize the intention to treat effect on farmers assigned to the market linkage treatment, we focus our discussion below, as well as our analysis of mechanisms, on the specification using 4 km spillover radius, in which the estimated effect of the market linkage treatment is maximized.

Using the 4 km radius specification, the estimated effect of the market linkage treatment on Aflasafe adoption is 8.6 to 8.7 percentage points (a 77–78% increase relative to adoption in control producer groups with no nearby groups assigned to the market linkage treatment). The estimated increase in the amount of Aflasafe purchased per farmer in market linkage groups is between 0.37 and 0.44 kg. This implies an increase in usage of between 140% and 198% relative to the amount used by comparison group farmers (those in control producer groups located further than 4 km

TABLE 5 Impact of market linkage treatment

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Binary adoption								
Controls for spillovers within radius:	none		2 km		4 km		6 km	
Market linkage	0.036	0.042	0.078[b]	0.067[b]	0.087[b]	0.086[b]	0.053	0.046
	(0.026)	(0.027)	(0.034)	(0.032)	(0.042)	(0.038)	(0.051)	(0.048)
Proportion of T villages within X KM*Control			0.106[b]	0.068	0.037	0.036	−0.019	0.006
			(0.051)	(0.057)	(0.049)	(0.046)	(0.061)	(0.058)
Proportion of T villages within X KM*Market linkage			−0.037	−0.025	−0.088[a]	−0.081	−0.058	−0.007
			(0.048)	(0.054)	(0.049)	(0.051)	(0.056)	(0.052)
Baseline controls	No	Yes	No	Yes	No	Yes	No	Yes
Villages	124	124	124	124	124	124	124	124
Observations	2713	2713	2713	2713	2713	2713	2713	2713
Mean of comparison group	0.127	0.124	0.097	0.106	0.112	0.111	0.136	0.123
Panel B: Amount purchased (kg)								
Controls for spillovers within radius:	none		2 km		4 km		6 km	
Market linkage	0.278[c]	0.257[c]	0.385[c]	0.296[c]	0.437[c]	0.372[c]	0.332[b]	0.243[a]
	(0.083)	(0.079)	(0.115)	(0.092)	(0.152)	(0.114)	(0.154)	(0.128)
Proportion of T villages within X KM*Control			0.290[b]	0.064	0.155	0.090	0.060	0.091
			(0.137)	(0.147)	(0.160)	(0.137)	(0.154)	(0.153)
Proportion of T villages within X KM*Market linkage			−0.037	−0.073	−0.228	−0.210	−0.094	0.114
			(0.168)	(0.171)	(0.174)	(0.175)	(0.209)	(0.180)
Baseline controls	No	Yes	No	Yes	No	Yes	No	Yes
Villages	124	124	124	124	124	124	124	124
Observations	2713	2713	2713	2713	2713	2713	2713	2713
Mean of comparison group	0.289	0.299	0.201	0.282	0.222	0.265	0.268	0.259

Note: Standard errors clustered at village level in parentheses;

[a]$p < 0.10$.

[b]$p < 0.05$.

[c]$p < 0.01$.

Note: The sample consists of farmer group members who were not surveyed at baseline, weighted by inverse probability of inclusion. Models with spillover controls include an indicator for no groups within the spillover radius. Baseline controls are those shown in Table A1. Comparison group means are calculated as the projection of regression coefficients for observations assigned to the control group with no other producer group within the spillover radius.

from any market linkage group). Among comparison group farmers who adopted, the mean purchase amount of Aflasafe was between 2 and 2.4 kg (dividing the mean quantity purchased, 0.265 kg with controls or 0.222 kg without, by the proportion adopting, 0.111 or 0.112). This quantity is sufficient to treat 0.5 to 0.6 acres of land, close to the mean value of 0.77 acres required to ensure safe maize for home consumption in a normal year based on the calculations in Section 4.5. Adopters in groups assigned to the market linkage treatment purchased an average of 3.2 to 3.3 kg (dividing the sum of the control group mean quantity purchased and the estimated treatment effect on this outcome with or without baseline controls ($= 0.265 + 0.372$, $= 0.265 + 0.372$) by the sum of the control group proportion adopting and the estimated treatment effect on adoption ($= 0.111 + 0.086$, $= 0.112 + 0.087$)). This quantity of Aflasafe is sufficient to treat between 0.81 and 0.83 acres and implies that a family would be closer to producing enough safe maize to cover their home consumption needs even if the harvest were poor (though still short of the mean poor harvest requirement of 1.3 acres).

Treatment effects estimated using the alternative samples (Appendix Tables A2–A5) are generally similar, though smaller and not significant using the smaller sample of farmers surveyed at baseline.

6.2 | Mechanisms

The finding of a positive treatment effect is consistent with both Proposition 1 (adoption increases because the premium is above the cost of achieving the required quality standard for some farmers) and Proposition 2 (adoption increases because the premium, although below the expected marginal cost of attaining the required quality per unit of expected output, increases the expected benefit of an investment made primarily to improve the quality of own consumption) in the model presented above. We use data from the endline survey on farmers' reported motivations for purchasing Aflasafe to distinguish between these two mechanisms and to test for other potential mechanisms through which the intervention could have affected adoption. Endline data are only available for the same farmers who were surveyed at baseline. We note as a caveat to this analysis that treatment effects on Aflasafe adoption and amount purchased were not significant in this subset (Appendix Table A3), though point estimates of the effect on adoption are nearly identical to those presented in Table 5.

Results are presented in Table 6. The first three outcomes, for which results (with and without baseline controls) are Columns 1 through 6, are binary indicators of farmers' stated reasons for purchasing Aflasafe (coded as zero for those who did not purchase). Regressing these on the treatment indicator and spillover controls shows that assignment to the market linkage treatment had no impact on the proportion of respondents who reported purchasing the product only to make the food household food safer (Columns 1 and 2). The effect of the premium on the share of farmers who adopted only for the sake of selling at a premium is small, at 1.2 to 1.4 percentage points, and only marginally significant ($p = 0.095$–0.056). A much larger impact, of 5 to 6 percentage points, is observed on the probability that farmers report adopting both to treat both own maize *and* to benefit from the premium price. These findings suggest that most of the observed impact on Aflasafe adoption generated by the modest premium offered in this experiment is driven by farmers who value the safety of food they consume themselves and for whom the market reward strengthens the expected benefit by increasing the value of excess safe produce.

Other mechanisms through which the intervention could potentially have affected adoption include its impact on farmers' level of aflatoxin knowledge, their level of health concern associated with the contaminant, or their beliefs regarding the efficacy of biocontrol. Such effects could arise if the opportunity to earn an incentive motivated farmers to remember general information about aflatoxin or specific information about the efficacy of Aflasafe provided during the first information session or if the existence of a premium conveyed information about buyers' concern about aflatoxin risk, which in turn amplified farmers' own worries about the health consequences of exposure.

We find that aflatoxin knowledge at endline was similar across treatment groups. Farmers also held similar beliefs about the efficacy of Aflasafe across treatment arms, with approximately 86% of those in both market linkage treatment and control groups reporting that the probability of aflatoxin contamination in treated maize was small at most, and 47–55% indicating no possibility of such a product failure.

Turning next to spillover effects, farmers' adoption of Aflasafe in nearby control villages appears to be entirely driven by the desire to have safe maize for own consumption rather than a misperception of eligibility for the quality premium. Noting the strong spillover impact on adoption

TABLE 6 Effect of market linkage treatment and proximity to treatment groups on stated reason for purchasing aflasafe, aflatoxin knowledge, and perceived chance of product failure

	Stated reason for adoption						Knowledge and efficacy perceptions					
Outcome variable:	Safety of own food only		Premium only		Safety of own food and premium		Aflatoxin knowledge		Small or no chance of Aflasafe failure		No chance of Aflasafe failure	
Market linkage (T)	−0.010	−0.012	0.012[a]	0.014[a]	0.060[b]	0.050[b]	−0.073	−0.065	−0.003	−0.001	−0.014	0.005
	(0.060)	(0.057)	(0.007)	(0.007)	(0.025)	(0.024)	(0.057)	(0.050)	(0.045)	(0.040)	(0.073)	(0.063)
Proportion of T groups within 4 KM ×C	0.144[a]	0.142[a]	−0.001	0.001	0.012	0.001	−0.062	−0.044	0.002	0.026	−0.060	−0.022
	(0.078)	(0.076)	(0.005)	(0.006)	(0.024)	(0.024)	(0.079)	(0.066)	(0.069)	(0.043)	(0.091)	(0.076)
Proportion of T groups within 4 KM× T	0.005	0.004	0.003	0.004	−0.031	−0.025	0.030	−0.014	−0.025	−0.047	−0.099	−0.129
	(0.073)	(0.070)	(0.014)	(0.013)	(0.036)	(0.036)	(0.087)	(0.071)	(0.051)	(0.051)	(0.090)	(0.078)
Baseline controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Villages	124	124	124	124	124	124	124	124	124	124	124	124
Observations	892	892	892	892	892	892	889	889	828	828	828	828
Mean of comparison group	0.269	0.270	0.000	−0.001	0.015	0.021	0.547	0.547	0.865	0.862	0.627	0.615

Note: Standard errors clustered at village level in parentheses;

[a] $p < 0.10$.

[b] $p < 0.05$.

[c] $p < 0.01$.

Note: The sample consists of farmer group members who were surveyed at baseline, equally weighted. Baseline controls are those shown in Table A1, without taking group means for variables measured through the baseline individual farmer survey. Comparison group means are calculated as the projection of regression coefficients for observations assigned to the control group with no other producer group within the spillover radius.

among the baseline survey subgroup (Appendix Table A3, Columns 1 and 2), we hypothesize that multiple sources of information about aflatoxin and Aflasafe, first through the baseline survey, then the information meeting, and finally from neighbors who shared information about the premium offer, could have increased the salience of health benefits associated with aflatoxin control and thus adoption among this group.

7 | DISCUSSION

In this paper, we derived a theoretical model showing how a price premium for a quality standard that is below the marginal cost of per expected unit of safe output attaining that standard can nonetheless increase adoption, both in terms of the intensity of investment and—in the presence of either a fixed cost of adoption or imperfect indivisibility of the technology—the proportion of farmers who adopt. Intuitively, a modest price premium increases the value of any safe food produced beyond that needed for home consumption. This causes an increase in the expected benefit of investing in the safety of farm produce when yield is unknown at the time the investment decision is made.

Economic theory on the role of agricultural production risk has long assumed that greater risk should, all else equal, imply lower input use (Just & Pope, 1978), and empirical investigations have focused on the role of downside risk in constraining the adoption of technologies that would, in expectation, increase farm income (Dercon & Christiaensen, 2011; Emerick et al., 2016; Rosenzweig & Binswanger, 1993). In this paper we describe the converse case: namely, how upside production risk can act as a diver of input use, by increasing the expected market return to a quality-enhancing input, even one that is not profitable.

We tested the predictions of this model by randomizing a price premium offer for maize compliant with the Kenyan regulation governing contamination with a common food safety hazard across producer groups in eastern Kenya. The value of the premium offered for safe maize was modest—approximately $1 USD per 90 KG bag, or 5% of the value of maize on the spot market. We find that this premium, which translated to an expected profit of less than $1 US for the median farmer, nonetheless increased the proportion of farmers who adopted a technology for control of the hazard by 75% and doubled the mean level of investment in this technology.

Analysis of farmers' stated reasons for investing in the food safety technology shows that, in line with the model's predictions about the effect of a low-value premium, most of those who adopted in response to the premium offer were motivated by both health concerns and the opportunity to sell at a premium. A smaller share of premium-induced adoption was based purely on the financial return, suggesting that relatively few farmers found investment in this technology to be a profitable strategy. Results reported by Deutschmann et al. (2021) showing that groundnut producers in Senegal who consumed a portion of the crop themselves were more likely than those who produced solely for sale to take up a food safety contingent contract also point to the importance of producers' health motivations.

The finding that a quality premium too low to induce adoption from a purely profit-maximizing standpoint can affect technology adoption among smallholders is relevant to food safety policy in developing countries in which subsistence production is widespread. If demand for food safety among higher income urban consumers can support even a low-value premium, this can have a significant impact on the amount of safe food produced, with positive health consequences for both subsistence producers and consumers of the premium product.

There are other settings in which small incentives, when aligned nonpecuniary motivations, could have outsized impacts on the production of public goods. For example, the opportunity to sell excess electricity generated through solar panels can complement consumers' principle-driven motivation to decarbonize their home energy use. The model presented in this paper provides a structure through which the complementary role of disparate behavioral drivers of technology adoption can be understood.

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ENDNOTES

[i] Personal communication, Paloma Fernandez, Cereal Millers Association of Kenya, December 21, 2021.

[ii] Good post-harvest handling and storage are also effective strategies for aflatoxin control. See for example Bauchet et al., 2021; Magnan et al., 2021; Pretari et al., 2019; Turner et al., 2005.

[iii] For simplicity, we assume that the marginal utility from consumption of the composite good and the price of the composite good equal 1. We thus implicitly express the value of home consumption in terms of in terms of the marginal utility from consumption of the composite good per unit of prices.

[iv] We assume constant marginal costs, so that c also is the marginal cost of treating land.

[v] We study dynamics on the short term, and therefore assume that no additional land can be brought into production.

[vi] In Section 2 of the online supplementary appendix we show that relaxing this assumption does not affect the propositions derived.

[vii] For tractability of the model, we assume below that the transaction cost of selling produce is greater than the difference between any market safety premium and the utility value of consuming safe maize. Relaxing this consumption does not affect the propositions derived.

[viii] We thus assume that delivering safe maize to the market results in a price premium with certainty. In Section 3 of the online supplementary appendix we relax this assumption and show that decreasing the probability that delivering safe maize to the market translates in a price premium will decrease the expected price premium. Our propositions continue to hold if we read "a price premium" as "an expected price premium."

[ix] If the transaction cost of selling maize is lower than $\delta - \beta_i$, farmers may apply the food safety technology to their entire cultivated area, sell their entire harvest, and buy maize from the market for home consumption. This possibility does not affect the propositions below.

[x] The mean level of contamination (as opposed to the probability of noncompliance with the standard required to obtain the premium for a particular farmer) is relevant both from a health and economic perspective, because most of the health burden of aflatoxin arises though cumulative exposure to moderate levels of the toxin over time and because maize is tested by processors in large lots.

[xi] The 152 groups were selected in a way that minimized the baseline differences in groups assigned to two insurance conditions (optional rainfall insurance or rainfall insurance bundled with Aflasafe) further described in subsection 4.2. This procedure is detailed in Section 5 of the online supplementary appendix.

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

[xiii] Although a full factorial design including a pure control, access to aflatoxin biocontrol, market linkage, and biocontrol plus market linkage would have been ideal, especially for evaluating treatment effects on aflatoxin contamination, we expected to see a significant interaction between the market linkage and biocontrol access on both Aflasafe adoption and aflatoxin contamination. In the presence of such interaction effects, each treatment would have to be compared against the pure control group (Muralidharan et al., 2019). Such a design would thus have severely reduced our power to detect impacts of the market linkage treatment on adoption.

[xiv] If fewer than six farmers were present at the census meeting, additional farmers were selected from among those listed as members but not present. In case any of the selected farmers were not available, replacements were selected from a randomly ordered list of six additional farmers, selected in the same fashion as the primary sample.

[xv] In 20 groups, it was not possible to interview six farmers and only five were interviewed.

[xvi] Maize samples were collected from farmers' stored maize at this time and were analyzed for aflatoxin by collaborators at IITA for use in an observational study, which is yet to be published. Variation in Aflasafe usage across treatments was not expected to be sufficient to allow for detection of causal impacts on aflatoxin contamination, which was therefore not prespecified as an outcome for the present study.

[xvii] As explained in Section 5, the sample used in the impact analysis consists of farmers who were listed during the farmer group census but not interviewed at baseline. Descriptive statistics presented in Table A1 and Table 5 are weighted by farmer group size as in the estimation of treatment effects.

[xviii] https://www.socialscienceregistry.org/trials/1373

[xix] Rainfall insurance was purchased by 89% of farmers; hence, we use the price of Aflasafe together with insurance (400 KSH per acre). The median wage for agricultural labor in the study area is 360/day, and the median time spent on application was one hour per acre. Based on conversations with key informants, we assume that an agricultural workday is six hours long. The median farmer cultivated one acre of maize.

[xx] For one group, the group census list was lost and retaken later. Although the group size had not changed, group composition may have changed. Excluding this group from the analysis does not affect the results.

[xxi] In the selection of survey respondents, preference was given to farmers who were present during the group census meeting. Farmers who were present are therefore under represented in this nonsurveyed subsample. We correct for this under representation by reweighting observations based on the likelihood of inclusion in the sample, given an individual's presence at the census meeting.

[xxii] The proportion of farmers in a group who were surveyed at baseline did not differ across treatment and control groups ($p = 0.627$).

[xxiii] All estimates are intention to treat. We cannot estimate the effect of treatment on the treated, as we do not have information on which farmers were aware of the premium price.

[xxiv] In addition to those listed in Table 2, X_{ij} includes a dummy indicating assignment to the bundled insurance treatment described in Hoffmann, Jones, and Leroy (2018). In the PAP, we indicated that the distance to the nearest market linkage group would be used to capture spillovers. However, this specification does not control for the influence of population density. As we find that the distance to nearest group (of either treatment) is correlated with Aflasafe adoption, we deviate from the prespecified spillover specification and instead use the proportion of market linkage groups within a given radius of each farmer group to control for spillovers.

[xxv] The distance to the closest group of the opposite treatment varies from 214 m to 21.5 km. 39% of control groups have at least one treatment group with 2 km, 70% have one within 4 km, and 88% have one within 6 km.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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