The (perceived) quality of agricultural technology and its adoption: Experimental evidence from Uganda

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Abstract

Recently, issues related to the (perceived) quality of inputs and technologies have been proposed as an important constraint to their adoption by smallholder farmers in low income countries. Taking maize seed embodying genetic gain as a case, we train random agro-dealers to test whether under-adoption by farmers is caused by low quality due to sellers' lack of knowledge about proper storage and handling. In a second hypothesis, we randomly introduce an information clearinghouse similar to popular crowd-sourced review platforms like yelp.com or trustpilot.com to test whether information asymmetries crowd out quality seed. We find that the clearinghouse treatment improves outcomes for both agro-dealers and farmers, with agro-dealers receiving more customers and reporting higher revenues from maize seed sales and farmers reporting significantly increased use of high-yielding maize seed varieties obtained from agro-dealers, leading to higher maize productivity after two seasons. The primary mechanisms behind this impact appear to be an increased effort to signal quality by agro-dealers and a general restoration of trust in the market for high-yielding seed. The agro-dealer training does not have a clear impact on agro-dealers, nor on farmers in associated catchment areas. Upon exploring interaction effects between both treatments, we find that the training becomes effective for agro-dealers that are also in the information clearinghouse treatment group. This underscores the importance of incentives to make supply side interventions such as trainings work.

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1 Introduction

The adoption of new agricultural inputs and technologies (such as seed embodying genetic gain, inorganic fertilizers, or agro-chemicals) remains tepid in areas where they can make the largest difference in terms of food security, poverty reduction, and biodiversity preservation (Suri and Udry, 2022; Gollin, Hansen, and Wingender, 2021; Borlaug, 2007). Several explanations for the low uptake of agricultural technology among small-scale, resource-poor farmers in low- and middle-income countries have been explored and tested with increasing depth and rigor in recent years. These include access to information about existence, use, and benefits of the technology (Ashraf, Giné, and Karlan, 2009; Van Campenhout, 2021); procrastination and time-inconsistent preferences (Duflo, Kremer, and Robinson, 2011); heterogeneity in the net benefits derived from the technology (Suri, 2011); missing markets for risk and credit (Karlan et al., 2014); and challenges related to learning about new technologies (Hanna, Mullainathan, and Schwartzstein, 2014).

More recently, issues related to the quality of inputs and technologies have been proposed as a key constraint to their adoption by smallholder farmers. Bold, Kaizzi, Svensson, and Yanagizawa-Drott (2017) build on the observation that farmers generally cannot easily assess quality from visual inspection at the time of purchase, so information asymmetries between sellers and buyers characterize the market for agricultural inputs. This in turn crowds out the market for quality inputs in Uganda—a similar lesson to the one we learned from Akerlof's seminal "Market for Lemons" study (1970). However, subsequent research suggests ambiguity about whether these quality issues should be attributed to agro-dealers intentionally adulterating their products, or whether they lack the requisite knowledge and skills to preserve quality (Barriga and Fiala, 2020). Furthermore, it is not always clear whether these quality issues are significant: While some studies argue that input quality is indeed lacking (Ashour et al., 2019), others argue that farmers may mistakenly perceive quality deficiencies even when the product meets the required standards (Michelson et al., 2021; Wossen, Abay, and Abdoulaye, 2022).

We investigate some of these issues through a field experiment conducted with both agro-dealers and smallholder farmers in their catchment areas in the nascent market for improved, high-yielding maize varieties in eastern Uganda.[1] We focus partly on agro-dealers because they are an essential marketing channel for inputs and technologies in countries with large smallholder farmer populations living in remote areas with poor infrastructure. A reasonably dense network of semi-formal agro-dealers provides access to seed, fertilizer, agro-chemicals, and tools, and may deliver agricultural advisory services and credit facilities, both formal or informal.

Yet small-scale agro-dealers may also be weak links in the supply chain for quality inputs. For instance, the semi-formal nature and scale of agro-dealers may mean they lack knowledge on proper handling and storage of agro-inputs. Barriga and Fiala (2020) document various issues related to handling and storage that may reduce input quality in the Ugandan seed supply chain. For example, agro-dealers often repack seed from larger bags packed by seed companies into smaller bags in order to offer quantities that are convenient and affordable to smallholders. As a result, important information including variety name, expiry date, or planting instructions is lost, while the material used for re-packaging—air-tight polyethylene bags—affects aeration, moisture, and seed viability. Other agro-dealers sell from open bags, which can similarly reduce seed via-

[1]In the context of this study, high-yielding maize varieties refer to both open-pollinated varieties and hybrids. While the distinction may be lost on some, it is a nuance that is recognizable to many colleagues working in the fields of plant breeding and seed sector development. For simplicity, we use the term "high-yielding varieties" to refer to genetically superior varieties, which may outperform in yield, germination rate, or maturity speed, as well as in tolerance to drought, pests, or diseases, among other traits.

bility (Bold, Kaizzi, Svensson, and Yanagizawa-Drott, 2017). In a first hypothesis, we thus posit that simply providing information to agro-dealers will increase seed quality and subsequently improve farmers' product experience, ultimately encouraging them to adopt high-yielding maize varieties.[2]

However, we recognize that providing information only to agro-dealers may not necessarily remedy the fact that seed quality cannot easily be observed by farmers. Furthermore, we expect that small-scale agro-dealers are subjected to less regulation and oversight than their larger counterparts in manufacturing, import, or wholesale operations situated further up the seed supply chain. This means that agro-dealers may still be incentivized—even with training—to underinvest in quality management and preservation. In a context similar to ours, Hoffmann et al. (2021) examine maize (grain, not seed) in rural Kenyan markets and find an absence of incentives for sellers to address food safety problems because they are not observable to their buyers. The same issue carries into seed markets, and in a worst-case scenario, agro-dealers may intentionally sacrifice quality to reduce costs and increase profits by mixing high-yielding or fresh seed with local or old seed, or even with grain, for example. Some evidence is consistent with this kind of adulteration and counterfeiting in Ugandan agricultural input supply chains. Bold, Kaizzi, Svensson, and Yanagizawa-Drott (2017) find that hybrid maize seed contains less than 50% authentic seeds and that 30% of nutrients are missing in fertilizer. Ashour et al. (2019) find that the average bottle of herbicide is missing 15% of the active ingredient and nearly one in three bottles contains less than 75% of the ingredient advertised.

But even in cases where agro-dealers provide quality inputs, the fact that quality cannot be easily assessed by farmers at the time of purchase may be problematic if farmers hold negatively skewed cognitive beliefs about seed quality sold by agro-dealers. Michelson et al. (2021) show that the nutrient content of inorganic fertilizers in Tanzania meets industry standards, but farmers nonetheless persist in their belief that it is adulterated. Wossen, Abay, and Abdoulaye (2022) show that farmers in Nigeria routinely misperceive the cassava variety they are cultivating and that efforts to address misperceptions could potentially improve farmers' investment choices and productivity outcomes.

In a second hypothesis, we conjecture that providing a signal about the quality of inputs sold by agro-dealers to both buyers and sellers will increase adoption through various mechanisms. First, buyers may shift from sellers that purportedly sell low-quality inputs to sellers that are said to provide high-quality inputs. Second, sellers may start to compete on quality, either by increasing quality if there is room for improvement, or by making the quality of their products more salient to buyers. Finally,

[2]It is important to note that our definition of maize seed quality extends beyond narrow criteria such as varietal purity (in other words, confirming the seed is of the expected variety) to include broader dimensions like seed germination and plant vigor. This is because, while some storage and handling practices may affect varietal purity (for example, mixing seed, mislabeling, etc.), most practices we will focus on in our study would affect seed performance. Furthermore, it is not unlikely that farmers care more about seed performance than about varietal purity.

in light of the new information, farmers may adjust their perceptions of the quality of inputs sold by agro-dealers.

The two hypotheses are tested in a randomized control trial (RCT) among 350 agro-dealers and associated 3,500 smallholder maize farmers in their catchment areas in eastern Uganda over the course of two agricultural seasons. The first hypothesis involves a fairly standard intervention where we provide a one-day training for agro-dealership owners and managers on proper storage and handling of seed. For the second hypothesis, we implement a decentralized information clearinghouse that is based on farmers' perceptions about the quality of inputs sold by agro-dealers. This information is then aggregated and made public, much like on yelp.com or tripadvisor.com. In particular, we ask farmers to rate agro-dealers and the products and services they offer, and use these ratings to construct scores and rankings, which we then disseminate back to both farmers and agro-dealers.

We find that the clearinghouse improves outcomes for both agro-dealers and farmers. Agro-dealers who were exposed to the information clearinghouse intervention receive more customers and have higher revenues from maize seed than agro-dealers in areas where the clearinghouse was not implemented. Farmers in areas where the information clearinghouse was rolled out are significantly more likely to use high-yielding maize varieties from agro-dealers and have higher yields than control farmers after two seasons. Impact seems to stem from clearinghouse-treated agro-dealers who increase their efforts and expand the services they provide to farmers. Treated agro-dealers are also more likely to be registered with the Uganda National Agro-input Dealers Association (UNADA), perhaps to signal quality now that it has been made salient to farmers. Finally, we find that farmers in the treatment group rate maize seed of agro-dealers in their neighborhood higher, suggesting that the information clearinghouse treatment is also effective in changing perceptions.

The agro-dealer training does not have a clear impact on agro-dealers, nor on farmers in associated catchment areas. Interestingly, we do find that the clearinghouse increases agro-dealer knowledge about proper seed storage and handling. Upon exploring interaction effects between the training and the information clearinghouse treatment, we find that the training is effective for agro-dealers who are also in the clearinghouse treatment group. This is consistent with Bold et al. (2022) who point out the importance of simultaneously addressing demand-side and supply-side constraints.

Our study contributes to a large literature on the effectiveness of providing training to small businesses in developing countries. Helping small firms to grow by teaching business skills has yielded mixed results when subjected to impact evaluation (for example, Karlan and Valdivia, 2011; Drexler, Fischer, and Schoar, 2014; Giné and Mansuri, 2021). While these studies often suffer from methodological issues such as low statistical power, some authors also argue that simply providing knowledge may be insufficient to move the needle (McKenzie and Woodruff, 2013). More promising results have emerged recently when the focus shifted away from traditional trainings and towards programs designed to instill personal initiative (Campos et al., 2017).[3] Our study similarly shows the importance of (external) motivation in making trainings effective.

We also add to the literature showing how the provision of product information to customers can solve the lemon problem through a variety of economic mechanisms. First, by enabling customers to screen for quality, they can now shift to better quality products. For instance, Lane, Schonholzer, and Kelley (2022) show that commuters in Nairobi choose safe buses after information on the safety records of different buses was made publicly available. Second, public disclosure of product information makes it possible for sellers to differentiate on quality, and indeed, start competing on it, which in turn lifts the market out of the low quality equilibrium. For example, Bennett and Yin (2019) show that the entry of a chain store (with a solid reputation for quality) leads to higher overall drug quality and lower prices in India. For the market for antimalarial drugs in Uganda, Björkman Nyqvist, Svensson, and Yanagizawa-Drott (2022) show that the presence of a non-governmental organization providing a superior product led to a stark reduction in the share of firms selling fake drugs.

Our study also contributes to a growing literature on the importance of social comparison, self-image, and social norms in determining behavior. Allcott and Rogers (2014) find that a social comparison-based intervention consisting of mailing reports of home energy use to households reduced their energy consumption dramatically. Gosnell, List, and Metcalfe (2020) report on an experiment with airline pilots where different strategies to increase fuel efficiency (including performance feedback and prosocial incentives) are tested. We suspect that, in addition to the threat of farmers shifting to better rated agro-dealers, psychological factors such as professional identity and a sense of social obligation may be important drivers for agro-dealers to improve.

The article further fits into an emerging literature that tests how crowd-sourced information can be used to reduce information asymmetries. Even though advances in Information and Communications Technology and the rise of e-commerce has led to numerous platforms that allow for customer feedback and a variety of websites that aggregate crowd-sourced reviews, there is surprisingly little evidence on the effects of these developments. The few rigorous studies that are available report impressive impact. Reimers and Waldfogel (2021) compare the effects of professional critics and Amazon star ratings of books on consumer welfare and find the effect of star ratings on consumer surplus to be more than ten times the effect of traditional (expert) review outlets. In the context of smallholder agriculture, Hasanain, Khan, and Rezaee (2023) implement a crowd-sourced information clearinghouse in the market for artificial insemination of livestock in Punjab, Pakistan, where individual signals of quality are noisy. They find that farmers who receive information enjoy 25% higher insemination success.

[3] Personal initiative is defined as a self-starting, future-oriented, and persistent proactive mindset.

2 Experimental design

We designed an experiment with two interventions (detailed in the next section) that aim to induce quality improvements (or perceptions thereof) in the seed market. The interventions are randomized at the agro-dealer catchment area level. These catchment areas are clusters of towns, villages, markets, trading centers, and other key market sheds where agricultural market activity tends to operate, and are typically host to several agro-dealers. Clustering agro-dealers into catchment areas is done on the basis of their geographical location.[4]

We randomize at the level of the catchment area (instead of opting for randomization at the less aggregate agro-dealer level) for three reasons. Firstly, randomizing at the level of the individual agro-dealer prompted ethical concerns. Specifically, in cases where two or more agro-dealers operate in very close proximity to each other, treating only one of them may lead to a competitive (dis)advantage. Randomizing at the catchment area level substantially reduces this risk. Secondly, and related to the first reason, catchment area level randomization reduces the likelihood of spillovers from treated to control agro-dealers. Thirdly, catchment area level randomization allows us to measure the impact of the interventions on farmers (and not just on agro-dealers) because all farmers in the catchment area are now exposed to agro-dealers who all received the same treatment.

We used simulations to determine the sample sizes required to detect effects of the treatments on selected outcomes at both farmer and agro-dealer levels.[5] The simulations show that if the number of catchment areas is larger than 112, our experiments will return statistically significant results 80% of the time on a selection of primary outcomes. This corresponds to approximately 318 agro-dealers. Based on further simulations to study impacts at the farm-household level, we decide to collect information on ten farmers per agro-dealer, leading to a sample size of 3,180 households.[6] The two interventions are combined in a field experiment that takes the form of a 2^2 factorial design.

[4]We use a haversine function to construct an adjacency matrix based on GPS coordinates, and agro-dealers who are less than five kilometers apart are assigned to the same catchment area. The five kilometer threshold was selected based on a visual inspection of a map, the size of an average village in our sample, and the reported distance between farmers and agro-dealers in survey data from a previous study of the maize value chain that can be found here.

[5]Simulation provides a flexible and intuitive way to analyze statistical power. Furthermore, instead of relying on theoretical distributions for the outcome variables that make assumptions and return analytic solutions, we run simulations that (re-)sample from real data collected in previous surveys. In particular, we use data from 78 agro-dealers and 1,529 smallholder farmers in the catchment areas of these agro-dealers from three districts in eastern Uganda in July 2019. The data are publicly accessible here.

[6]More detailed information, including the expected treatment effect sizes, can be found in the pre-analysis plan which was pre-registered at the AEA RCT registry under RCT ID 0006361.

3 Interventions

3.1 Agro-dealer training

Training content and material

To determine the content of the training and to ensure it is sufficiently anchored in the study site and context, we consulted experts from several Ugandan organizations using semi-structured interviews and a workshop to identify problems in the seed sector and in agro-dealer retailing practice as well as to discuss effective and realistic solutions and best practices to address seed storage and handling issues. We then developed a training manual to ensure a standardized treatment and a simple but visually appealing poster illustrating the most important practices. Participants in the interviews and workshops included individuals from the Ministry of Agriculture, Animal Industries and Fisheries (MAAIF), the National Agricultural Research Organization (NARO), the Uganda Seed Trade Association (USTA), and the Uganda National Agro-Dealers Association (UNADA). The roll-out of the experiment began with the implementation of the first treatment in 2021 (Figure 1).

Training

In each treated catchment area, all agro-dealers were selected for the training, and for each treated agro-dealer, both owner and shop manager were invited. The owner was invited because several recommended techniques and practices required that new investments were made in the agro-dealership, while the shop manager was invited because many of the recommendations are hands-on practices that would ultimately fall under the manager's purview for day-to-day operations. Of the 166 invited agro-dealers, 140 sent at least one person, leading to a compliance of 84%.[7]

The training took place in May 2021, a time when agro-dealers were not too busy and early enough to ensure they could apply newly learned practices in the second agricultural season. Trainings were held in locations that were easily reachable for the agro-dealers and organized in small groups, with an average of 10-15 agro-dealers participating. To deal with COVID-19 responsibly, participants and trainers were required to keep proper distance, wear face masks, and frequently disinfect their hands. All attendants were compensated for transport, and lunch and refreshments were provided. Participants were further incentivized to engage in the training and pay close attention with an offer of a free portable seed moisture meter, so long as they passed a short knowledge test comprised of a series of multiple-choice questions at the end of the training.[8] The agro-dealers were also given a copy of the informational poster used in the training to take to their shops and remind them of best practices.

[7]For 80 agro-dealers, both owner and manager attended; for 50 agro-dealers, only the owner attended; for ten agro-dealers, only the manager attended.

[8]This was done to encourage attendants to pay attention but every agro-dealer who attended received a moisture meter, regardless of how they scored on the test.

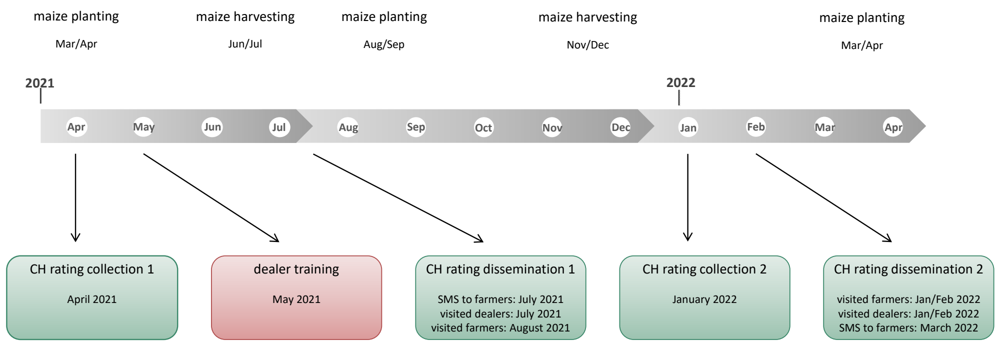

Figure 1: Timeline

In each training, the trainers explained correct handling and storage practices for high-yielding maize seed and used the poster and an example seed bag for illustration. Participants then rehearsed the more challenging practices like measuring moisture using a moisture meter. The trainings were organized and conducted in collaboration with UNADA.

3.2 Information clearinghouse

Rating collection and computation

At the time of baseline data collection (April 2021), we asked sampled farmers to rate all agro-dealers operating in the catchment area on multiple characteristics. Enumerators were guided by a tablet-based application that iterated through all agro-dealers in the catchment area. We provided the common names used to refer to each agro-dealer, a description of where their store is located, and a picture of the store front (obtained during the agro-dealer census—see Subsection 5.1). If farmers knew the agro-dealer, they were asked to provide ratings using the questions listed in Table 1. For example, we asked farmers to rate "maize seed that the agro-dealer sells" on a scale of one to five

Table 1: Questions for farmers to rate agro-dealers

	min	max
Do you know this *shop name* or *dealer name*, sometimes called *nickname*, located in *market name*? The place can be described as *description*.	no	yes
Please rate this agro-dealer on:		
Quality and authenticity of seed	1 star	5 stars
Please rate the maize seed that this agro-dealer sells on:		
General quality	1 star	5 stars
Yield as advertised	1 star	5 stars
Drought tolerance as advertised	1 star	5 stars
Pest/disease tolerance as advertised	1 star	5 stars
Speed of maturing as advertised	1 star	5 stars
Germination	1 star	5 stars

stars on seed germination.[9] Based on the answers of all farmers in a catchment area, we computed an average rating for each agro-dealer. These ratings were translated into both words and star ratings to ensure that they were easily comprehensible to farmers and agro-dealers when disseminated. See Appendix A.1 for details on the rating computations.

A potential concern arises from asking treated farmers to rate agro-dealers because it may increase awareness among farmers of the existence of all agro-dealers in the area, such that this awareness effect could confound the information clearinghouse effect. To address this concern, we also iterated through the agro-dealers in the catchment areas with farmers in the control group to make them similarly aware of the existence of agro-dealers in their vicinity. However, control farmers were not asked to rate agro-dealers as the process of rating an agro-dealer's seed could make quality more salient, which we consider to be a key aspect of the treatment.

As shown in Figure 1, we implemented the clearinghouse in two consecutive seasons, so ratings were collected again in January 2022. Ratings were always collected *after* harvest, when smallholders were able to assess seed quality based on observing germination and yield; the resistance against droughts; pests and diseases; and how quickly the crop matured.

[9] We acknowledge that agro-dealers stock different varieties, so that asking farmers to assess the quality of seed in general may mask some of the trade-offs customers may face. It would have been ideal to ask farmers to rate agro-dealers conditional on variety, manufacturer, and form sold (for example, to rate "Bazooka" produced by Naseco in an original two-kilogram bag). However, this would have made the rating process much more tedious and time consuming. Instead, we opted to test a scalable solution that generates a general signal of seed quality at the agro-dealer level.

Rating dissemination to farmers

Our ability to test the effectiveness of the information clearinghouse treatment depends on the timing of the dissemination of these agro-dealer ratings. Dissemination occurred before farmers started buying seed for the next agricultural season, allowing treated farmers to use the new rating information when choosing whether and where to purchase inputs (Figure 1). Ratings were disseminated to farmers through short message service (SMS) and in person, as detailed below.

Text messages Farmers received one text message per agro-dealer in their catchment area by SMS in one of three local languages—Lusoga, Lugwere, or Samia. For farmers in treatment catchment areas, the message read:

> Hello from AgroAdvisor! Did you know that customers from [*name of the agro-dealer*] rate the quality of maize seed sold there as [*okay/good/very good/excellent*]?

To isolate the effect of the ratings from more general effects that may arise from sending text messages, we use a placebo for the control group that consists of an "empty" SMS that only points out the existence of agro-dealers in the control farmer's catchment area. This also makes it more difficult for farmers to identify if they are being treated or not, thus reducing the likelihood of reactivity effects and experimenter bias.

In person In addition to the text messages, enumerators re-visited the farmers in our sample. For this purpose, we designed a visually appealing tablet-based application that cycles through all agro-dealers in the catchment area of each farmer and provides their ratings. The application generates the following statement:

> We wanted to let you know that customers from [*name of the agro-dealer*] rate the quality of maize seed sold there as [*okay/good/very good/excellent*]! The quality of the maize seed that this agro-dealer sells received a score of [*score*] out of 5!

The application also displayed one to five stars associated with the score. Again, for control group farmers, the application cycled through the agro-dealers in the control areas without providing ratings to control for any effect that may arise from simply being reminded of the existence of these agro-dealers.

Rating dissemination to agro-dealers

Agro-dealers received their ratings in the form of a report on laminated paper that was delivered to their agro-dealerships. The front of the report shows a visually appealing certificate with a logo and the agro-dealer's general rating (Figure 2). We encouraged agro-dealers to prominently display their rating in the agro-dealership, like a "certificate of excellence" from TripAdvisor or similar rating apps.

Figure 2: SeedAdvisor certificate

The back of the report provides additional information, including the individual ratings that the seed sold by the agro-dealer received for overall quality, yield, drought and disease resistance, maturation speed, and germination, and the average (combined) ratings of other agro-dealers in the same catchment area in a table, visualized by stars. This shows agro-dealers their relative position in the area, potentially motivating them to improve their ratings through social comparison and self-image effects.

The entire process of collecting and disseminating ratings was completed twice, the first time targeting the second agricultural season of 2021 and the second time targeting the first agricultural season of 2022 (see Figure 1). Repeating the treatment was essential to capture the varying dynamics of specific impact channels on certain outcomes. For instance, if seed is good but farmers hold pessimistic beliefs about its quality, disseminating information may already result in increased adoption and yield effects after a single season. However, if agro-dealers engage in counterfeiting, the threat of farmers switching to more honest competitors may lead agro-dealers to improve quality, which would be reflected in subsequent ratings. These higher ratings could increase adoption, but the effect on yields would only become apparent during harvest in the second season. Repetition may also be important for the effectiveness of certain impact pathways. For instance, agro-dealers may be more likely to change their behavior if they know that they will be scored again in the near future. To avoid end-game effects, farmers and agro-dealers were kept unaware of how long the clearinghouse would be implemented.

4 Empirical strategy

We estimate intention-to-treat effects on outcomes at both the agro-dealer level and the farmer level. To increase power, we condition the estimates on (mean-centered) baseline values of the outcome variables. We estimate the following specification using Ordinary Least Squares to obtain the average treatment effects for agro-dealer level outcomes:

$$Y_{ij} = \alpha + \beta T_j + \gamma' X_{ij} + \delta Y_{0ij} + \varepsilon_{ij} \tag{1}$$

where Y_{ij} is the outcome for agro-dealer i in catchment area j at midline or endline, Y_{0ij} is the corresponding outcome at baseline, T_j is a dummy for the treatment status of catchment area j, X_{ij} is a vector of controls for the orthogonal treatments in the factorial design (demeaned and interacted with the main treatment effect, see Lin, 2013; Muralidharan, Romero, and Wüthrich, 2023), and ε_{ij} is an error term that is potentially correlated within catchment areas. The coefficient β is the estimated average treatment effect. For farmer level outcomes, a similar equation is estimated, where Y_{ij} is now the outcome variable for farmer i in catchment area j at midline or endline, Y_{0ij} is the corresponding outcome at baseline, and all other terms are defined as in the agro-dealer regression above.

Because we randomize at the catchment area level, we use cluster-robust variance-covariance matrices that cluster standard errors at this level. For outcomes at the farmer level where we have almost 3,500 observations in 130 clusters, the original form of the sandwich estimator that does not make any small-sample correction is used. For outcomes at the agro-dealer level where we have almost 350 observations in 130 clusters, we use the Bell–McCaffrey adjustment (Imbens and Kolesár, 2016).

We also follow several pre-registered principles for variable construction. For continuous variables, trimmed values are used to reduce the influence of outliers. In particular, we trim 1% of each side of the distribution for agro-dealer level outcomes and 2.5% of each side of the distribution for farmer level outcomes. Inverse hyperbolic sine transformations are used if variables are skewed, with skewness being defined as the adjusted Fisher–Pearson coefficient of skewness exceeding 1.96. Outcomes for which 95% of observations have the same value within the relevant sample are omitted from the analysis.

We account for multiple hypothesis testing by aggregating different outcomes within a family into summary indices, following Anderson (2008).[10] While these indices are useful to judge the overall impact of the intervention on a family of outcomes, it is not straightforward to interpret the effect size. Focusing on individual outcomes within each family reveals more meaningful effect sizes and highlights the variables driving the

[10] Each index is computed as a weighted mean of the standardized values of the outcome variables. The weights of this efficient generalized least squares estimator are calculated to maximize the amount of information captured in the index by giving less weight to outcomes that are highly correlated with each other.

Table 2: Factorial design

		Agro-dealer training	
		1	0
Clearinghouse	1	33 areas 96 agro-dealers 960 farmers	32 areas 97 agro-dealers 970 farmers
	0	33 areas 70 agro-dealers 700 farmers	32 areas 85 agro-dealers 850 farmers

results. This is why we also report the treatment effects on individual variables, though we advise care in interpretation.

5 Data

5.1 Sample

The agro-dealer sample was obtained by listing all agro-dealers in eleven districts in southeastern Uganda. After this census, the resulting 348 eligible agro-dealers were assigned to 130 catchment areas (for details, see Section 2, Footnote 4 in particular). This procedure led to an average of three agro-dealers per catchment area, ranging from a minimum of one to a maximum of 18.

To connect agro-dealers to farmers, we asked them for the names of the villages where most of their customers come from. Then enumerators were instructed to randomly sample ten households that grow maize in these villages. Consequently, about 3,500 smallholder maize farmers were sampled. Allocation of farmers, agro-dealers, and catchment areas to the different treatment cells of the factorial design is summarized in Table 2.

Baseline data were collected from agro-dealers in September and October 2020 and from farmers in April 2021. Midline data from both farmers and agro-dealers were collected in January and February 2022, and endline data from farmers and agro-dealers were collected in July and August 2022.

At the agro-dealer level, enumerators were instructed to interview the person who is most knowledgeable about the day-to-day operations of the agro-dealership, which was usually the shop manager. As part of the initial quality assessment process, a bag of maize seed was purchased at each agro-dealer.[11,12] Enumerators also noted a series of objectively verifiable quality indicators related to seed storage.

At the farmer level, enumerators were instructed to interview the person most knowledgeable about maize farming. However, a set of questions deals with the household head, who could or could not be the respondent. In addition to general questions about farming and input use, farmers were asked to enumerate all their maize plots, from which a random plot was chosen, and detailed data was collected on that plot.[13]

5.2 Descriptive statistics

This subsection describes the baseline sample. Information about the average agro-dealer can be found in Table 3. The average respondent is 32 years old, 60% are male, and more than 90% finished primary education. In 55% of the cases, the respondent is also the owner of the agro-dealership.

We see substantial heterogeneity among agro-dealers. Some are small informal stores that are located in rural areas and sell maize seed and other agricultural inputs in addition to consumer items to a small customer base and only during the planting season. Others have many customers, are located in towns and only sell inputs and equipment used in agricultural production. The average agro-dealership was established five years prior to the baseline survey, is located seven kilometers from the nearest tarmac road, and services 41 customers per day. Among the sampled agro-dealers, 74% sell only farm inputs and equipment, 60% reported that they provide credit, and 46% that they offer advisory services.

Information was also collected to provide an initial assessment of the quality of maize seed sold at the sampled agro-dealers. This included specific questions on seed storage and handling. Furthermore, with the shop manager's permission, enumerators—who were trained to do so at the outset of the study—inspected the area where seed was stored and carefully recorded the conditions. Baseline data reveals various signs that seed storage and handling are sub-optimal and may affect seed quality in line with our first hypothesis. For example, we find that 65% of agro-dealers had problems with pests such as rats or insects, while 16% store maize seed in open containers, thus exposing the seed to a range of pests and contaminants. Not surprisingly, two-thirds of the agro-dealers sampled reported that they had received at least one complaint about seed they sold from a customer during the prior season.

Our measurements of moisture content in the bags of sampled seed obtained from the agro-dealers indicated an average of 13.6%, with a minimum of 10.3% and a maximum

[11]Unfortunately, only 232 of the 348 sampled agro-dealers had seed in stock at the time of the baseline interview.

[12]Even though repackaging seed from original larger bags from seed companies into smaller bags to offer quantities that are convenient and affordable to their clients is common (around half of the agro-dealers in our sample report to do so), the samples that enumerators bought were all original, sealed bags.

[13]This was mainly done to reduce data collection costs, time, and burden. As plots were chosen randomly, averages should be representative at the household level.

of 17.4%. On average, these moisture contents were above the recommended content of 13%, suggesting potential for the growth of molds and storage pests that can negatively affect seed quality and performance.[14] In terms of labeling for quality, 68% of the purchased seed bags contained a printed packaging date, 18% had an expiry date, and 8% displayed a quality indication label issued by the National Seed Certification Services (NSCS).[15]

Table 4 reports means in the farmer sample. The average household head in our sample is 49 years old; 78% are male and 51% have finished primary education. The average household size is nine people, and the typical homestead is located four kilometers from the nearest agro-dealer and nine kilometers from the nearest tarmac road. The average farmer has 23 years of experience cultivating maize and grows crops on three acres of land.

Half of the farmers in our sample planted high-yielding maize seed on at least one of their plots in the season preceding the baseline survey (the August-December 2020 season), with one out of three farmers purchasing this seed at an agro-dealer. Only 25% applied inorganic fertilizers such as di-ammonium phosphate (DAP) or nitrogen, phosphorus, and potassium (NPK) on the randomly selected plot. Average yields on these plots were about 440 kilograms per acre in the season preceding the baseline survey.

5.3 Orthogonality tests of randomization balance

We include standard orthogonality tables with pre-registered variables for both agro-dealers and farmers to test if treatment and control groups are comparable in terms of a set of baseline characteristics (Tables 3 and 4, respectively). Some of these characteristics are unlikely to be affected by the intervention, while others are drawn from the set of outcome variables that will be used to measure the intervention's impact and explore the underlying mechanisms at play in the next sections.

For outcomes at the agro-dealer level reported in Table 3, we find that from a total of 34 comparisons, only one is significant at the 5% significance level and two are significant at the 10% level. For outcomes at the farmer level reported in Table 4, out of 32 comparisons, one is significant at the 10% level. We conclude that this shows reasonable balance at baseline. We also test for joint orthogonality using F-tests, which confirm balance between treatment groups.

[14] Moisture is a powerful predictor of maize seed performance. For instance, Afzal et al. (2017) report germination rates of about 85% for seed with a moisture content of 12.7% versus germination rates of only 50% for the same seed with a moisture content of 15.6% in a study in Pakistan. Experts we consulted to develop the training on proper seed handling and storage follow this rule of thumb: an increase of moisture by one percentage point reduces shelf-life by half.

[15] Typically, maize seed is certified by NSCS, a division of the Department of Crop Inspection and Certification in MAAIF. Certified seed is identified by a blue tag or sticker affixed to the package, and quality-declared seed is marked by a green tag or sticker.

Table 3: Descriptive statistics and orthogonality tests - Agro-dealer

	mean	training	CH
Respondent's age in years†	32.43	0.56	-2.24+
	(11.49)	(1.19)	(1.21)
Respondent is male†	0.59	0.02	-0.01
	(0.49)	(0.06)	(0.06)
Respondent finished primary education†	0.92	0.01	-0.01
	(0.27)	(0.03)	(0.03)
Respondent owns shop	0.55	0.03	0.02
	(0.50)	(0.06)	(0.06)
Respondent received training on maize seed handling†	0.53	0.05	0.12+
	(0.50)	(0.07)	(0.07)
Respondent knows how to store seed after repackaging†	0.27	0.07	0.08
	(0.44)	(0.06)	(0.06)
Agro-dealer's distance to nearest tarmac road in km†	6.56	-0.92	-1.58
	(10.39)	(2.21)	(2.24)
Agro-dealer only sells farm inputs	0.74	-0.09	0.03
	(0.44)	(0.07)	(0.06)
Years since agro-dealer establishment†	5.34	-0.09	0.21
	(6.30)	(0.77)	(0.78)
Number of customers per day†	41.49	11.35	6.43
	(46.49)	(7.16)	(6.72)
Quantity of maize seed sold in kg†	695.50	201.06	176.31
	(1497.18)	(252.97)	(235.92)
Amount of maize seed lost/wasted last season in kg†	3.50	1.99	2.40
	(18.65)	(2.47)	(2.30)
Number of maize varieties in stock	2.83	-0.28	0.19
	(1.59)	(0.22)	(0.21)
Agro-dealer has problem with pests	0.65	-0.01	-0.03
	(0.48)	(0.06)	(0.06)
Agro-dealer stores maize seed in open containers	0.16	0.00	0.08
	(0.36)	(0.05)	(0.05)
Agro-dealer received seed related complaint from customer	0.64	-0.11*	0.07
	(0.48)	(0.05)	(0.05)
Moisture in bag of maize seed in %	13.56	0.25	-0.18
	(1.44)	(0.25)	(0.26)

Note: Column (1) reports sample means at baseline and standard deviations below; columns (2)-(3) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; **, *, and + denote significance at the 1%, 5%, and 10% levels. † indicates that the variable was pre-registered to test balance and is included in the F-test.

Table 4: Descriptive statistics and orthogonality tests - Farmer

	mean	training	CH
Household head's age in years†	48.62	-0.08	-0.24
	(13.38)	(0.56)	(0.56)
Household head is male†	0.78	-0.02	0.03
	(0.42)	(0.03)	(0.03)
Household head finished primary education†	0.51	0.00	0.04
	(0.50)	(0.03)	(0.03)
Homestead's distance to nearest tarmac road in km	9.39	0.33	-1.23
	(10.81)	(1.69)	(1.71)
Homestead's distance to nearest agro-dealer in km†	3.78	-0.11	0.11
	(4.79)	(0.37)	(0.37)
Number of people in household (incl. respondent)†	8.70	-0.16	-0.09
	(3.98)	(0.18)	(0.18)
Number of rooms in house	3.49	-0.01	0.02
	(1.45)	(0.09)	(0.09)
Farmer's land for crop production in acres	3.35	0.07	0.00
	(4.32)	(0.21)	(0.22)
Years since farmer started growing maize	23.09	0.61	-0.55
	(13.14)	(0.55)	(0.58)
Yield in kg/acre†	443.01	27.15+	-6.14
	(304.99)	(13.71)	(13.52)
Farmer used quality maize seed on any plot†	0.49	0.02	0.01
	(0.50)	(0.02)	(0.02)
Farmer bought this seed at agro-dealer†	0.32	-0.01	0.01
	(0.47)	(0.02)	(0.02)
Amount of this seed farmer bought at agro-dealer in kg†	9.52	0.16	-0.34
	(6.92)	(0.53)	(0.53)
Farmer thinks maize seed at agro-dealer is adulterated†	0.68	0.01	0.00
	(0.46)	(0.03)	(0.03)
Farmer used DAP/NPK	0.25	0.04	0.02
	(0.43)	(0.03)	(0.04)
Farmer used organic manure	0.07	-0.01	0.01
	(0.26)	(0.01)	(0.01)

Note: Column (1) reports sample means at baseline and standard deviations below; columns (2)-(3) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; **, *, and + denote significance at the 1%, 5%, and 10% levels. † indicates that the variable was pre-registered to test balance and is included in the F-test. Amount of this seed farmer bought at agro-dealer was pre-registered to test balance but is not included in the F-test because the question was only asked if a farmer bought seed at an agro-dealer, leading to 2406 missing observations for this variable.

5.4 Attrition

Table 5 reports attrition levels in the treatment and comparison groups. We failed to collect data from 12% of agro-dealers and 2% of farmers at midline, and from 14% of agro-dealers and 1% of farmers at endline.[16] To test if non-response is related to one of the treatments, we regress the likelihood of leaving the sample on the treatment indicators. We find that information clearinghouse treated agro-dealers are significantly less likely to leave the sample.

To examine this differential attrition, we run regressions with the variables that were pre-registered to test balance (see Table 3) as dependent variables and a binary variable that takes the value one if an agro-dealer left the sample, a binary variable that takes the value one if an agro-dealer belongs to the clearinghouse control group, and the interaction between these two indicators as independent variables. The results can be found in Appendix A.2. Column (2) shows that agro-dealers who left the sample at midline operate closer to the nearest tarmac road. This is the only significant difference between agro-dealers who left and those who did not at midline, when differential attrition was most pronounced, see Table 5. At endline however, agro-dealers who left the sample were younger, more likely to be female, and their shops were less long in business, more likely to be specialized, and operated closer to the nearest tarmac road, see column (5). This implies that agro-dealers who left are different from those who stayed, independent of whether they have been exposed to the information clearinghouse or not. We conjecture that these agro-dealers were more vulnerable when COVID-19 hit and went out of business. Columns (3) and (6) show that clearinghouse control and treated agro-dealers do not differ much, which is also described in Subsection 5.3. When we look at the interaction between the two indicators, we observe that there are few differences between agro-dealers who both left the sample *and* belong to the information clearinghouse control group and those who do not, so we conclude that differential attrition is unlikely to bias our estimates.

As in biomedical RCTs where differential attrition rates may be due to excess mortality in the control group, the attritors are likely the ones that would have benefited most from the treatment. As such, the unadjusted selection-contaminated estimates provide lower bounds for the true treatment effect (Angrist, Bettinger, and Kremer, 2006; Duflo, Glennerster, and Kremer, 2007).

6 Results

We now present impact of the two interventions on both agro-dealer level outcomes and farmer level outcomes. We separately report effects after one agricultural season (referred to as impact at midline) and after two seasons (referred to as impact at endline).

[16] If an agro-dealer could not be found at endline, we investigated why: eleven shops closed, ten relocated, eight were located but sell different products now, three merged with other shops, one agro-dealer did not want to be interviewed, 17 agro-dealers reported another (four) or no reason (13).

Table 5: Attrition

	mean	training	CH
		midline	
Agro-dealer left the sample	0.121	-0.007	-0.108**
	(0.326)	(0.034)	(0.035)
Farmer left the sample	0.018	-0.005	0.001
	(0.134)	(0.005)	(0.005)
		endline	
Agro-dealer left the sample	0.144	0.017	-0.079+
	(0.351)	(0.040)	(0.042)
Farmer left the sample	0.008	-0.003	-0.001
	(0.091)	(0.003)	(0.003)

Note: Column (1) reports sample means at mid- or endline and standard deviations below; columns (2)-(3) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; **, *, and + denote significance at the 1%, 5%, and 10% levels.

For reasons of transparency and replicability, all outcome variables are described in the registered pre-analysis plan which can be found in the American Economic Association's registry for RCTs. In addition, before midline data collection, the entire econometric analysis was run on simulated data and also registered in a mock report (Humphreys, De la Sierra, and Van der Windt, 2013).[17] All documents, code, and data are under revision control and publicly accessible in a GitHub repository which provides time-stamped records of all changes made over the course of the project.[18]

Tables 6 to 15 present results in a common layout. Column (1) provides baseline sample means with standard deviations in parentheses to help gauge effect sizes.[19] In column (2), we provide the average treatment effect of the agro-dealer training at midline, while column (3) reports the average treatment effect of the information clearinghouse at midline. Standard errors are reported in parentheses below the coefficient

[17] A mock report is a dynamic report that integrates all code, such that when midline and endline data become available, one simply has to replace the simulated data with the real data. We use the knitr engine to integrate R code in LaTeX (Xie, 2017).

[18] The presentation of results in this paper differs somewhat from the way it was pre-registered and presented in the mock report (and midline report, endline report, and previous versions of this manuscript). In particular, we reorganized the presentation of results to match a structure where we first look at impact on outcomes at the end of the causal chain and then look at impact on intermediate outcomes to explore potential mechanisms. While this change does affect the construction of some of the pre-registered indices, overall conclusions remain the same. Several pre-registered tables can be found in Appendix A.3. The analysis that follows the pre-registered structure can be found in the project history on GitHub, for instance here.

[19] Note that these means are reported in levels to allow the interpretation of effect sizes, even though we may report the difference between treatment and control groups after using inverse hyperbolic sine transformations.

estimates. Column (4) reports the number of observations used in the estimations at midline. Columns (5) and (6) report average treatment effects of the training and the clearinghouse treatment respectively at endline, that is, after two seasons. Again, we report standard errors in parentheses below the coefficient estimates. Column (7) reports the number of observations used in the endline estimations. As noted in Section 4, we account for multiple hypothesis testing by aggregating different outcomes within families into overall summary indices, following Anderson (2008). Results for these indices are reported at the bottom of the tables.[20]

6.1 Impact on agro-dealers

We start by testing if the interventions affected general business operations of agro-dealers (Table 6). A measure of sales volume was constructed by asking agro-dealers how much of a specific maize variety they sold in the previous season. We restrict attention to the four most popular high-yielding varieties, two of which are hybrids (Longe 7H and Longe 10H) and two of which are open pollinated varieties (OPVs) (Longe 4 and Longe 5). The total quantity sold is the combined sum of the quantities sold for these four varieties. We also asked agro-dealers about the sales price of the four varieties at the start of the season and then calculated the simple average. We calculate revenue (expressed in million Ugandan shillings) by first multiplying prices with quantities sold and then summing over the four varieties.[21] We also include the number of customers that bought maize seed on an average day at the start of the season, as well as the number of maize varieties the agro-dealer had in stock.

Table 6 shows that we do not find an impact of training agro-dealers on their business operations. At both midline and endline, the impact on the index is not significantly different from zero. No particular pattern emerges to explain these insignificant results, and there is little significance among the outcome variables when estimated separately. At midline, we find a negative impact of the training on the average sales price. At endline, the training seems to have reduced amounts sold, which is also reflected in a lower revenue.

We do find a positive impact of the information clearinghouse intervention on agro-dealer operations. At midline, the business operations index is significantly higher among agro-dealers in the clearinghouse treatment group. Looking at individual outcomes, treated agro-dealers sold more maize seed at a higher price, albeit not significantly so. However, in combination, this led to revenues that are almost 20% higher, and this difference is significant at the 10% level.[22] At endline, the positive effect of

[20] In the regressions with these overall indices, we do not control for the baseline values because this would imply having the result only for agro-dealers and farmers who have no missing values for any of the variables constituting these indices at midline/endline and at baseline, severely reducing statistical power.

[21] One dollar was about 3600 Ugandan shillings at the time of the study.

[22] For sufficiently large values, the coefficients of regressions with a dependent variable that has been transformed using the inverse hyperbolic sine can be interpreted as elasticities (Bellemare and Wichman, 2020).

the information clearinghouse intervention seems to become stronger, with the effect on the overall index now being significant at the 1% level. The effect is driven by a 31% increase in the number of customers that a treated agro-dealer attracts, which translates into six additional customers per day.

The next set of results focuses on the effect of the interventions on operations related to two particular varieties, specifically, the most recently released hybrid (Longe 10H) in Table 7 and the most recently released OPV (Longe 5) in Table 8. In addition to the already described business operation outcomes, we include outcomes related to stock management, given that seed quality decreases with shelf-life. We asked agro-dealers how much of the particular seed was carried over from the previous season. Many agro-dealers reported that they did not carry over any seed, leading to low baseline means. Furthermore, we asked the agro-dealers to estimate how much they bought from any provider during the same season. For both varieties, this is slightly more than what agro-dealers reported to have sold. We expect our treatments to decrease the amount of seed carried forward and increase the amount of fresh seed procured from providers. We also asked the agro-dealers to estimate how much of their seed stock was lost or wasted during the season, and how often they ran out of stock. We expect the interventions to reduce both losses and stock-outs.

For both varieties, we do not find significant effects of the training nor the clearinghouse treatment at midline. At endline however, all individual coefficient estimates move in the expected direction for the information clearinghouse, and when outcomes are combined in an index, the effect is positive and statistically significant.

Moving one step further up the impact chain, we explore whether reported increases in the number of customers, sales, and revenues are likely driven by an improvement in the quality of maize seed sold by these agro-dealers. To do so, we instructed enumerators to buy a random bag of seed from each agro-dealer. This bag was then inspected on a range of attributes (bag integrity, lot number, packaging date, shelf-life, etc.) and moisture was measured. Our quality tests of the purchased seed did not indicate any effects, although due to the fact that not all agro-dealers had seed in stock, we are likely to face statistical power issues. More information can be found in Appendix A.4.

6.2 Impact on smallholder farmers

We first investigate harvest-related outcomes for farmers and report the results in Table 9. We start by examining production, plot size, and production scaled by plot size (in other words, yield) on a randomly selected maize plot. We also look at market participation (amount sold, sales price, and revenue from maize sales) and how much grain farmers save to use as seed in the next season. While we expect positive effects on harvest and sales, the amount kept as seed enters the index negatively.

The coefficient estimates for the overall index show no effect of the agro-dealer training, and a positive effect of the clearinghouse, albeit only after two seasons of implementation. Farmers that live in areas where the information clearinghouse was implemented report higher production and productivity at endline than control farmers

Table 6: Effects on agro-dealer outcomes: Operations

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Quantity of maize seed sold in kg§†	695.503	-0.092	0.284	292	-0.499^{+}	0.239	286
	(1497.183)	(0.220)	(0.227)		(0.250)	(0.253)	
Sales price of maize seed in UGX/kg†	4273.897	-192.784^{+}	99.272	275	-33.867	145.861	264
	(955.073)	(114.934)	(113.292)		(143.152)	(138.816)	
Revenue from maize seed in mln UGX§†	2.890	-0.069	0.185^{+}	292	-0.227^{+}	0.143	286
	(6.286)	(0.104)	(0.108)		(0.118)	(0.118)	
Number of maize seed customers per day§†	19.764	-0.056	0.127	294	-0.190	0.310**	288
	(20.689)	(0.098)	(0.101)		(0.116)	(0.112)	
Number of maize varieties in stock†	2.834	0.042	0.245	295	-0.216	0.221	292
	(1.589)	(0.266)	(0.245)		(0.234)	(0.220)	
Overall index	0.031	-0.130	0.197*	274	-0.131	0.238**	270
	(0.610)	(0.095)	(0.092)		(0.086)	(0.082)	
Max. number of obs.				306			297

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.
§Due to the skewness of this variable, the regression was run after an inverse hyperbolic sine transformation. Coefficient estimates can therefore be interpreted as percentage changes. The baseline mean column shows the untransformed variable.

Table 7: Effects on agro-dealer outcomes: Operations - Longe 10H

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Quantity sold in kg§†	288.384	0.050	0.236	256	-0.205	0.352	242
	(727.049)	(0.206)	(0.204)		(0.231)	(0.239)	
Sales price in UGX/kg§†	9.417	-0.025	-0.013	194	-0.019	0.010	187
	(0.145)	(0.026)	(0.026)		(0.030)	(0.029)	
Revenue in mln UGX§†	1.625	0.008	0.130	255	-0.106	0.173	241
	(3.839)	(0.119)	(0.123)		(0.130)	(0.136)	
Amount carried over in kg§†	2.679	-0.186	0.090	262	-0.012	-0.034	250
	(12.137)	(0.212)	(0.215)		(0.138)	(0.134)	
Amount shop bought from provider in kg§†	294.672	0.118	0.206	257	-0.022	0.283	243
	(741.810)	(0.218)	(0.213)		(0.250)	(0.253)	
Amount lost/wasted in kg§†	0.036	-0.001	0.019	257	-0.058	-0.038	243
	(0.405)	(0.093)	(0.097)		(0.037)	(0.041)	
Number of times per month shop ran out§†	1.039	-0.236^{+}	-0.045	192	-0.180	-0.205	185
	(1.575)	(0.129)	(0.133)		(0.128)	(0.136)	
Overall index	0.080	0.030	0.029	244	0.021	0.217**	233
	(0.437)	(0.067)	(0.070)		(0.052)	(0.057)	
Max. number of obs.[1]				268			254

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

§Due to the skewness of this variable, the regression was run after an inverse hyperbolic sine transformation. Coefficient estimates can therefore be interpreted as percentage changes. The baseline mean column shows the untransformed variable.

[1]The comparisons were only made for agro-dealers that had Longe 10H in stock at mid- or endline.

Table 8: Effects on agro-dealer outcomes: Operations - Longe 5

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Quantity sold in kg§†	389.492	-0.040	0.304	261	-0.215	0.316	259
	(716.556)	(0.222)	(0.216)		(0.234)	(0.230)	
Sales price in UGX/kg§†	8.730	0.017	-0.015	249	-0.002	0.013	241
	(0.110)	(0.016)	(0.016)		(0.022)	(0.022)	
Revenue in mln UGX§†	1.193	0.019	0.111	261	-0.080	0.114	258
	(2.175)	(0.099)	(0.096)		(0.100)	(0.105)	
Amount carried over in kg§†	4.312	0.247	-0.092	270	-0.095	-0.004	263
	(19.088)	(0.324)	(0.306)		(0.148)	(0.155)	
Amount shop bought from provider in kg§†	431.451	-0.005	0.253	262	-0.179	0.289	260
	(803.696)	(0.221)	(0.215)		(0.232)	(0.235)	
Amount lost/wasted in kg§†	1.756	-0.150	0.031	266	-0.055	-0.033	261
	(10.173)	(0.128)	(0.128)		(0.055)	(0.058)	
Number of times per month shop ran out§†	0.839	0.053	0.086	248	0.094	-0.054	237
	(1.509)	(0.100)	(0.101)		(0.120)	(0.126)	
Overall index	0.039	0.037	0.012	256	-0.038	0.152*	252
	(0.401)	(0.068)	(0.062)		(0.058)	(0.058)	
Max. number of obs.[1]				275			269

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

§Due to the skewness of this variable, the regression was run after an inverse hyperbolic sine transformation. Coefficient estimates can therefore be interpreted as percentage changes. The baseline mean column shows the untransformed variable.

[1]The comparisons were only made for agro-dealers that had Longe 5 in stock at mid- or endline.

that live in areas where the clearinghouse was not implemented. Yield differences are significant at the 1% level and amount to 13% of the baseline mean. Finally, we look at the amount of maize that farmers retain for seed in the next season. At midline, we see that, in line with expectations, information clearinghouse treated farmers save less grain for seed.

To further explore the large and significant effect of the clearinghouse on yields, we investigate whether specific subgroups of farmers experienced more yield gains than others. Rerunning the regression only for farmers who did not adopt at baseline led to a coefficient of 56.44 with a standard error of 17.38 (hence, significance at the 1% level). For farmers that did adopt at baseline, we find a coefficient of 30.79 with a standard error of 20.38 (hence, no significance). This indicates that the effect is plausibly driven by farmers who did not use high-yielding maize seed at baseline, started using it due to the information clearinghouse treatment, and, in turn, realized higher yields.

Moving up on the causal chain, we test if the interventions affect the use of quality maize seed as a second important family of outcomes at the smallholder level. For the agro-dealer training, we do not find any significant effect at either midline or endline. The effect of the clearinghouse treatment on overall use (or "adoption" for convenience) as measured by the index is positive and significant at the 5% level at midline and endline.

Zooming in on individual outcomes, we start with a subjective assessment of adoption by asking farmers if they "used any quality maize seed (like an OPV or hybrid seed) on any of their plots". We see that at midline, farmers who were subjected to the information clearinghouse treatment were 3.5 percentage points more likely to answer this question affirmatively than control farmers. After two agricultural seasons, the difference between treatment and control farmers increases to 4.2 percentage points. Relatedly, we ask if farmers bought high-yielding maize varieties at an agro-dealer for any plot. At midline, we find a difference of about six percentage points between the clearinghouse treatment and control groups, and this amounts to an almost 20% increase relative to the baseline mean. At endline, the difference is about three percentage points, but not significant. We do not find an impact of the information clearinghouse on the amount of seed that farmers bought at agro-dealers. However, note that estimates are based on a small sample size (n=599 at midline and n=621 at endline) as this question was only asked if farmers had purchased seed from an agro-dealer.

Next, we turn our attention to the use of quality maize seed on a randomly selected plot. For the use of seed from either hybrid maize varieties or OPVs, we find positive treatment effects of the clearinghouse, although the coefficients are insignificant.[23] As for the more general questions above, we also ask if the seed used on the random plot was obtained from an agro-dealer. We find an almost five percentage point treatment effect for the information clearinghouse at midline and an almost four percentage point

[23] Here, we asked farmers which variety they planted in the previous season. If a farmer used Longe 10H, Longe 7H, Longe 7R/Kayongo-go, Bazooka, Longe 6H, Longe 5/Nalongo, Longe 4, Panner, Wema, KH series, or other hybrid/OPV, and this seed was not recycled or farmer-saved but newly purchased, it counted as hybrid maize seed/OPV.

Table 9: Effects on farmer outcomes: Harvest on specific maize plot

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Production in kg†	463.203	-0.806	-20.372	2884	16.959	43.937*	2898
	(399.595)	(14.050)	(14.529)		(17.957)	(17.922)	
Area in acres	1.094	-0.013	-0.003	3004	0.000	0.006	3066
	(0.655)	(0.029)	(0.029)		(0.032)	(0.038)	
Yield in kg/acre†	443.013	-12.216	-23.006	2878	5.549	55.606**	2891
	(304.991)	(16.234)	(16.964)		(15.573)	(17.283)	
Amount sold in kg§†	195.295	-0.046	-0.201	3063	-0.147	0.173	3137
	(297.545)	(0.126)	(0.124)		(0.159)	(0.173)	
Sales price in UGX/kg	506.954	-7.787	33.027*	610	-47.215	12.614	639
	(139.389)	(14.395)	(14.244)		(30.547)	(41.238)	
Revenue in UGX§†	97.783	-0.141	-0.393	3058	-0.354	0.355	3109
	(156.538)	(0.260)	(0.257)		(0.341)	(0.363)	
Amount kept as seed in kg§	14.506	-0.098	-0.188*	2931	-0.043	0.036	2861
	(18.530)	(0.092)	(0.092)		(0.108)	(0.104)	
Overall index	-0.020	-0.015	-0.061	2932	0.018	0.097*	2900
	(0.784)	(0.039)	(0.039)		(0.041)	(0.041)	
Max. number of obs.				3407			3441

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

§Due to the skewness of this variable, the regression was run after an inverse hyperbolic sine transformation. Coefficient estimates can therefore be interpreted as percentage changes. The baseline mean column shows the untransformed variable.

effect at endline. Conversely, we estimate the clearinghouse effect on the use of farmer-saved seed on the randomly selected plot. In line with our expectations, we find that farmers who were exposed to the information clearinghouse treatment reduced their use of saved seed, albeit only significantly so at midline. Finally, we examine the product of the amount and the price of maize seed, in other words, the total expenditure on seed for the plot. We see that in areas where the clearinghouse was implemented, farmers invest significantly more in seed.

7 Causal chain and mechanisms

For the agro-dealer training, the underlying mechanism is fairly straightforward: this treatment potentially changes agro-dealer knowledge and behavior through learning, which results from exposure to and uptake of new and salient information. The information clearinghouse is a multifarious intervention that solves a variety of potentially interlinked information problems simultaneously. If the quality of maize seed is sufficient but some farmers believe that agro-dealers provide sub-standard products, a clearinghouse may correct their perceptions. If the quality of seed differs between agro-dealers, the information clearinghouse provides farmers with information which may help them to switch to agro-dealers who provide better quality. Furthermore, the rating system directly incentivizes agro-dealers to stay ahead of immediate competitors. They can do so by improving the quality of the products they offer, or by signaling that the quality of their products is good. In this section, we investigate the relative importance of these different impact pathways.

7.1 Agro-dealer knowledge

Learning is the primary mechanism underlying the training, which is in turn expected to increase the knowledge of treated agro-dealers. To test if the interventions affected agro-dealer knowledge, we construct two indices that summarize different dimensions of knowledge. The first index aims to measure knowledge about seed storage and handling. We use a short multiple choice quiz of five questions related to seed carryover between agricultural seasons, how seed should be stored after repackaging, how seed should be stored in the storeroom, and whether seed should be repackaged. The exact questions, the options presented to farmers, and the correct answers are outlined in Appendix A.5.

The second knowledge index aims to capture knowledge about seed more broadly. We again use multiple choice questions to test if agro-dealers know which seed variety to recommend if a farmer complains about poor soil or lack of rain, if a farmer is late for planting, and whether they know what to tell clients who inquire about the yield benefits of hybrid varieties or OPVs. Again, the questions and (correct) answer options are explained in Appendix A.5.

These indices are useful to test if there are significant knowledge differences between treatment groups. However, they are less useful for assessing agro-dealer knowledge

Table 10: Effects on farmer outcomes: Adoption

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Farmer used high-yielding seed on any plot†	0.492	-0.021	0.035^{+}	3206	-0.009	0.042*	3282
	(0.500)	(0.020)	(0.020)		(0.020)	(0.020)	
Farmer bought seed at agro-input shop for any plot†	0.325	-0.014	0.059**	3145	0.004	0.031	3225
	(0.468)	(0.021)	(0.021)		(0.019)	(0.020)	
Amount of this seed farmer bought at agro-input shop in kg	9.519	0.512	-0.105	599	0.457	0.378	621
	(6.920)	(0.348)	(0.358)		(0.419)	(0.431)	
Farmer used hybrid seed/OPV on specific plot[1]†	0.432	-0.019	0.035	2954	0.009	0.030	3047
	(0.495)	(0.023)	(0.023)		(0.023)	(0.023)	
Farmer bought seed at agro-input shop for specific plot†	0.330	-0.010	0.047*	3153	0.012	0.036^{+}	3240
	(0.470)	(0.022)	(0.022)		(0.019)	(0.019)	
Farmer used farmer-saved seed on specific plot	0.579	0.020	-0.042^{+}	3153	-0.009	-0.016	3240
	(0.494)	(0.022)	(0.022)		(0.020)	(0.020)	
Cost of seed used on specific plot in UGX§†	14078.272	-0.181	0.499*	2848	0.283	0.350^{+}	2942
	(24654.685)	(0.235)	(0.235)		(0.208)	(0.209)	
Overall index	-0.013	-0.030	0.087*	2854	0.015	0.086*	2978
	(0.899)	(0.043)	(0.042)		(0.039)	(0.039)	
Max. number of obs.				3407			3441

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

[1]For this variable, only non-recycled (newly purchased, not farmer-saved) seed counted as hybrid variety/OPV.

§Due to the skewness of this variable, the regression was run after an inverse hyperbolic sine transformation. Coefficient estimates can therefore be interpreted as percentage changes. The baseline mean column shows the untransformed variable.

at baseline, and indices may mask subtle differences in effects on individual answers. In Appendix A.6, we therefore provide baseline means and effects on the different knowledge variables included in the indices. Baseline knowledge is low with only 5% of agro-dealers knowing which variety to recommend if a farmer complains about lack of rain. Highest knowledge is recorded when we ask about repackaging seed: 64% of agro-dealers know that this practice should be avoided. This low baseline knowledge suggests ample room for improvement.

Table 11 suggests a positive impact of the agro-dealer training on knowledge at midline, but the coefficient is just shy of significance at the 10% level. The (insignificant) effect of the training is strongest at midline, which seems reasonable as the training was organized only once at the start of the study (see Figure 1). Interestingly, we find knowledge effects from the clearinghouse treatment, particularly for agro-dealer knowledge related to seed storage and handling. This effect becomes stronger over time, which again seems reasonable as this treatment was repeated. This result suggests that the information clearinghouse treatment, with its focus on seed quality, prompts agro-dealers to actively search for information on better ways to store and handle seed.

These results suggest that providing only knowledge through training is unlikely to improve outcomes when demand-side constraints are binding, echoing Bold et al. (2022). In our setting, extra knowledge at the agro-dealer level is only useful if farmers are able to observe and appreciate the consequences of it (see also Hoffmann et al., 2021). To explore this further, we exploit the factorial design of the experiment, and focus on the subset of agro-dealers that was assigned to both the training and the clearinghouse treatment. We indeed find significant positive interaction effects on key outcomes at the agro-dealer level at endline (most notably on the overall operations index, as in Table 6). The positive interaction effect seems to be driven by significant improvements in efforts and practices (as in Table 12). However, note that these exploratory results should be interpreted with care, as we are possibly underpowered to test interactions. More details regarding interaction effects are available from the authors upon request.

7.2 Agro-dealer efforts, services, and practices

The information clearinghouse provides agro-dealers with an incentive to become better than their direct competitors to attract more farmers (Lane, Schonholzer, and Kelley, 2022). Furthermore, the performance feedback provided through the treatment may motivate agro-dealers to become better and increase quality through behavioral channels such as social comparison and self-image effects (Gosnell, List, and Metcalfe, 2020).

Agro-dealers could attempt to improve quality by changing the way they store and handle seed. In addition, and particularly if they already use appropriate storage and handling methods, they may increase effort and start providing more or better services

Table 11: Effects on agro-dealer outcomes: Knowledge

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Index of dealer knowledge about seed storage[1†]	0.000	0.091	0.115	306	0.030	0.124*	297
	(0.482)	(0.076)	(0.075)		(0.053)	(0.055)	
Index of dealer knowledge about seed[2†]	0.000	0.102	0.065	306	-0.009	-0.007	297
	(0.533)	(0.072)	(0.070)		(0.080)	(0.078)	
Overall index	0.000	0.208	0.211^{+}	306	0.038	0.142	297
	(0.729)	(0.125)	(0.119)		(0.107)	(0.102)	
Max. number of obs.				306			297

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

[1]The index of dealer knowledge about seed storage contains 5 variables: whether dealer knows how long seed can be carried over, how seed should be stored after repackaging, what the min. distance between floor and seed is, how seed should be stored in storeroom, whether seed should be repackaged.

[2]The index of dealer knowledge about seed contains 4 variables: whether dealer knows which seed variety to recommend if farmer complains about poor soil, if farmer complains about little rain, if farmer is late for planting, what to tell clients about yield benefits of hybrid seed.

in an attempt to (indirectly) affect ratings.[24]

In Table 12, we provide evidence that agro-dealers who are exposed to the clearinghouse indeed invest more effort than agro-dealers in the control group. The table shows results for one overall index and four individual indices that each capture different dimensions of effort, services, and practices. The first index focuses on effort and service provision as reported by agro-dealers themselves, and is composed of seven variables: whether the agro-dealer (1) offers explanations on how to use the seed they sell to farmers, (2) recommends complementary inputs to get optimal results from high-yielding varieties, (3) provides advisory services or training, (4) offers discounts for large-quantity purchases, (5) offers credit, (6) received a seed-related customer complaint since the preceding season, and (7) accepts mobile money payments. A second index summarizes the perceptions of farmers who purchase from these agro-dealers. This index is also constructed from seven variables: whether an agro-dealer (1) offers refunds or insurance, (2) provides credit, (3) offers training or advice to customers, (4) delivers to the farmgate, (5) provides after-sales service, (6) accepts different payment methods, and (7) sells small quantities. Farmers' answers to these questions are aggregated at the agro-dealer level before the index is computed.

To handle and store seed correctly, a combination of investments and labor-intensive practices is necessary. During the agro-dealer training, we also recommended a mix of practices within the reach of different types of agro-dealers, some of which may have excess labor while others may have access to money to invest. A third index groups a set of labor-intensive seed handling and storage practices. It contains six variables: whether seed is stored (1) in a dedicated area, (2) in correct lighting, (3) on appropriate surfaces, and (4) not in open containers, (5) whether the agro-dealer has a pest problem, and (6) how clean and professional the agro-dealership looks. These data were collected by enumerators through visual inspection. A fourth index summarizes capital-intensive seed handling practices, based on six variables: whether the roof is (1) leak-proof, (2) insulated, (3) whether the walls are insulated, (4) whether the agro-dealership is ventilated, (5) whether the agro-dealership displays any official certificate, and (6) whether expired seed is handled correctly. Most of these variables were collected or at least confirmed by enumerators through visual inspection. Only one of them (whether expired seed is handled correctly) is self-reported.[25]

We find that the information clearinghouse intervention increases agro-dealer effort and services, especially at midline, where the coefficient of the overall index is significant at the 1% level. This overall effect is driven by treated agro-dealers who significantly

[24]For example, if agro-dealers already provide quality inputs but farmers complain about low yields, they may provide training/advice and recommend complementary inputs to get optimal results. This could increase yields, in turn improving farmer perceptions of seed quality. Or, agro-dealers may provide insurance or cash back guarantees, which may then be interpreted by farmers as a signal of high quality.

[25]To test whether social desirability affects this result, we exclude the last variable from the index and rerun the analysis, given that agro-dealers might report that they handle expired seed correctly but, in reality, choose not to do so for strategic reasons such as cost management. Doing this does not change the coefficients for the index of capital-intensive seed handling practices.

raised their effort and services, according to farmers. We see that the impact persists until endline, where the significant effect on the overall index seems to be driven by the self-reported measure of effort. We do not find that the agro-dealer training improves services or practices.

In markets characterized by asymmetric information, signaling is often used to solve the inefficiency problem (Spence, 1973). In our case, as it is difficult to assess seed quality via visual inspection, agro-dealers may use various strategies to signal to customers that their products are of good quality. Becoming a member of professional organizations is one way to do so. Agro-dealers who try to signal quality will also not shy away from inspections. On the contrary, they may actively seek inspection so that they can advertise the result in their agro-dealerships.

Table 13 collects a set of variables related to signaling quality, including memberships in UNADA and other professional associations, trading licenses, the number of inspections in the preceding season, and warnings or confiscations of seed after inspection. We find that at endline, judging by the overall index, the clearinghouse treatment led to a significant increase in compliance with or participation in quality signaling measures. Looking at the individual outcomes, the overall effect seems to be driven by an increase in registrations with UNADA. Agro-shops often display their UNADA certificates, potentially to inform inspectors and customers about their registration to signal professionalism and quality. We also see that treated agro-dealers were inspected significantly more often. We do not find any effects of the agro-dealer training.

7.3 Switching

An important potential mechanism underlying the effect of the information clearinghouse is the possibility that farmers switch from lower rated agro-dealers to higher rated ones. To explore this mechanism, we asked farmers if they switched agro-dealers since the previous season. Results in Table 14 indicate that only 17% of farmers reported switching at baseline. However, at midline, a significantly higher share of farmers in the clearinghouse treatment group reported switching agro-dealers. Also at endline, we find a higher propensity for switching among information clearinghouse treated farmers.

However, an increased likelihood to switch does not necessarily mean that farmers move from lower-rated agro-dealers to higher-rated ones. To investigate this, we calculate the difference between the rating of the agro-dealer the farmer is switching to and that of the agro-dealer the farmer is switching from. If farmers move to better-rated agro-dealers, this difference would be positive. We find that this is indeed the case, and more so during the second season, although the difference is not significantly different from zero at conventional levels (p-value = 0.166).[26]

At the agro-dealer level, we find that the clearinghouse treatment led to a significant increase in the number of customers (Table 6). This cannot be explained by farmers switching, since switching involves an increase in customers for some agro-dealers at

[26]This analysis is available from the authors upon request.

Table 12: Effects on agro-dealer outcomes: Efforts and practices

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Index of dealer efforts and services, self-reported[1†]	0.000	-0.063	0.066	243	-0.031	0.086^{+}	297
	(0.454)	(0.062)	(0.060)		(0.051)	(0.048)	
Index of dealer efforts and services, according to farmers[2†]	-0.027	-0.151^{*}	0.301^{**}	259	0.006	0.086	271
	(0.583)	(0.074)	(0.069)		(0.092)	(0.084)	
Index of labor-intensive seed handling practices[3†]	0.010	0.058	0.099	285	0.083	0.074	274
	(0.484)	(0.070)	(0.065)		(0.067)	(0.068)	
Index of capital-intensive seed handling practices[4†]	0.000	-0.019	0.000	270	-0.087	0.070	265
	(0.508)	(0.063)	(0.072)		(0.092)	(0.081)	
Overall index	0.032	-0.029	0.359^{**}	189	0.006	0.165^{+}	234
	(0.540)	(0.121)	(0.113)		(0.099)	(0.091)	
Max. number of obs.				306			297

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

[1]The index of dealer efforts and services, self-reported contains 7 variables: whether shop offers explanations, complementary input recommendations, extension/training, discounts for larger quantities, credit, did not receive seed related customer complaint, accepts mobile money.

[2]The index of dealer efforts and services, according to farmers contains 7 variables: whether shop offers refund/insurance, credit, training/advice, delivery, after-sales service, accepts different payment methods, sells small quantities. The answers are aggregated at dealer level, then the index is computed.

[3]The index of labor-intensive seed handling practices contains 6 variables: whether seed is stored in dedicated area, in correct lighting, on correct surface, not in open containers, whether shop has no pest problem, cleanness and professionality rating by enumerator.

[4]The index of capital-intensive seed handling practices contains 6 variables: whether roof is leak-proof, roof is insulated, walls are insulated, shop is ventilated, shop displays official certificate, expired seed is handled correctly.

Table 13: Effects on agro-dealer outcomes: Memberships, licenses, inspections

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Shop is registered with UNADA†	0.442	0.040	0.066	252	-0.050	0.118^{+}	258
	(0.497)	(0.072)	(0.068)		(0.072)	(0.070)	
Shop is member of other professional association†	0.345	-0.035	0.058	268	0.001	0.069	267
	(0.476)	(0.051)	(0.052)		(0.073)	(0.066)	
Shop has trading license issued by local government†	0.749	-0.042	0.021	288	-0.033	0.008	285
	(0.435)	(0.053)	(0.054)		(0.056)	(0.057)	
Number of shop inspections§†	1.532	0.037	-0.097	293	0.038	0.292^{*}	273
	(1.859)	(0.247)	(0.259)		(0.109)	(0.111)	
Shop received warning after inspection†	0.317	0.045	0.005	291	0.013	-0.009	284
	(0.466)	(0.072)	(0.073)		(0.062)	(0.063)	
Shop's products were confiscated after inspection†	0.145	0.021	-0.027	293	0.014	-0.025	285
	(0.353)	(0.046)	(0.046)		(0.033)	(0.036)	
Overall index	-0.004	-0.005	0.047	266	-0.006	0.203^{**}	253
	(0.433)	(0.056)	(0.055)		(0.078)	(0.074)	
Max. number of obs.				306			297

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

§Due to the skewness of this variable, the regression was run after an inverse hyperbolic sine transformation. Coefficient estimates can therefore be interpreted as percentage changes. The baseline mean column shows the untransformed variable.

Table 14: Effects on farmer outcomes: Switching behavior

	midline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Farmer switched to different agro-input shop	0.168	-0.013	0.042**	3407	-0.024	0.026+	3441
	(0.374)	(0.014)	(0.014)		(0.015)	(0.015)	
Max. number of obs.				3407			3441

Note: Column (1) reports midline means and standard deviations below (because this variable was not collected at baseline); columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

the expense of others, leaving the average number of customers of agro-dealers in the treatment group unaffected. When we look at changes in customers over time, we do not see that the increase is largest for agro-dealers with high ratings. This suggests that the impact of the information clearinghouse treatment on perceptions—to which we turn next—may be particularly important for agro-dealers with low ratings, offsetting any potential loss that is caused by the switching mechanism.

7.4 Perceptions

Finally, the clearinghouse may change farmer perceptions of the quality of seed sold by agro-dealers. Table 15 shows the impact on two measures of farmer perceptions of quality. First, we asked farmers if they think that maize seed that can be bought at agro-dealers is counterfeit or adulterated. We intentionally kept this question general—that is, about maize seed which can be bought at any agro-dealer without specifying a particular variety—to obtain an overall idea about farmers' sentiments regarding maize seed at agro-dealers. At baseline, two in three farmers responded affirmatively to this question, indicating substantial pessimism about quality. Columns (2) to (5) show the impact of the information clearinghouse for the full sample. The treatment does not significantly affect farmer perceptions as measured by this variable at midline or endline. However, we expect the effect of the clearinghouse on perceptions to be strongest for farmers who did not use high-yielding maize varieties at baseline.[27] Therefore, we repeat the analysis for this subgroup of farmers in columns (6) to (9). At midline, farmers who did not adopt at baseline and live in areas exposed to the information clearinghouse are 12.5 percentage points less likely to think that agro-dealers sell adulterated seed than similar farmers in areas not assigned to the treatment.

Second, we investigate rating data to assess farmer perceptions of product quality, conditional on specific agro-dealers. In particular, we look at the index of maize seed ratings that combines scores for general quality, yield, drought tolerance, pest and disease tolerance, time of maturity, and germination of seed obtained from various agro-dealers.[28] These ratings are aggregated at the farmer level (since one farmer generally rates multiple agro-dealers), and then, the index is calculated.[29] We see that the index is positively and significantly affected by the information clearinghouse treatment, even though the effect is only significant at the 10% level. If we restrict the sample to farmers who did not adopt high-yielding maize varieties at baseline, the treatment effect on the ratings is significant at the 5% level. The impact on the overall index that combines the two perception related indicators is also significant for this sub-sample.

This improvement in farmers' opinions and ratings may reflect a real increase in the

[27]Note that this subgroup analysis was not pre-registered and is of exploratory nature.

[28]As the act of rating agro-dealers was an essential part of the clearinghouse treatment, we only collect ratings in control areas at endline, implying that we can test this hypothesis only at endline.

[29]To compute this index at the farmer level, we restrict the sample to farmers that have rated at least one agro-dealer in the catchment area on all components of the index. This procedure leads to a sample size reduction, which in turn may affect statistical power.

Table 15: Effects of the clearinghouse on farmer outcomes: Perceptions

		full sample				*sub-sample*			
	baseline	*midline*		*endline*		*midline*		*endline*	
	mean	CH	obs.	CH	obs.	CH	obs.	CH	obs.
Farmer thinks seed at agro-dealer is adulterated†	0.685	-0.041	2113	0.020	2167	-0.125**	903	0.010	944
	(0.465)	(0.027)		(0.028)		(0.036)		(0.035)	
Index of farmer's seed ratings of agro-dealers in area[1]†	0.000			0.092^{+}	1664			0.141*	693
	(0.637)			(0.054)				(0.063)	
Overall index	0.019			0.104	1462			0.160*	596
	(0.770)			(0.071)				(0.074)	
Max. number of obs.			3407		3441		1719		1741

Note: Column (1) reports baseline means and standard deviations below; columns (2) and (4) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (3) and (5) report number of observations; columns (6) to (9) mirror this structure for the sub-sample of farmers that did not adopt at baseline, **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

[1]The index of farmer's maize seed ratings contains 6 ratings: general quality, yield, drought tolerance, pest/disease tolerance, time of maturity, germination. The ratings are aggregated at farmer level (one farmer rates multiple agro-dealers), then the index is computed. Note that treatment and control groups can only be compared at endline. At base- and midline, only clearinghouse treated farmers rated dealers in their proximity because being confronted with these questions is part of the treatment. Hence control dealers were not rated and this line is left blank at midline. At endline, all farmers rated all agro-dealers, so that this variable can be investigated.

quality of seed if the clearinghouse improved agro-dealers' seed handling practices, in turn improving seed quality. However, Appendix A.4 shows that we do not find clear evidence that the information clearinghouse treatment affected a set of (imperfect) quality proxies of the seed agro-dealers sell. Furthermore, looking at Table 12, we find no evidence that agro-dealers change seed handling or storage in response to the clearinghouse treatment. As such, the change in quality perceptions does not seem to reflect a real change in quality.

An alternative explanation is that the quality of maize seed at most agro-dealers in our sample is sufficient but (non-adopting) farmers misperceive it. This is in line with Michelson et al. (2021) and Wossen, Abay, and Abdoulaye (2022) who establish that input quality is generally good but farmers' beliefs are often incorrect, meaning that simply rectifying their misperception would increase adoption. Consistent with this explanation, we find that two in three farmers thought that maize seed at agro-dealers is counterfeit or adulterated at baseline. At the same time, the average agro-dealer was rated 3.4 out of five at baseline, which indicates that perceived seed quality was reasonable. An explanation for this discrepancy could be that the full sample (including farmers who never purchased seed at agro-dealers) was asked about the prevalence of counterfeit or adulterated maize seed at agro-dealers, while the farmers who rate have experience with seed from agro-dealers. Because of the information clearinghouse treatment, mostly non-adopting pessimistic farmers notice that adopting peers do not share their pessimism, and they adjust their perceptions. Furthermore, the clearinghouse affects several measures of adoption already at midline. If we assume that changing agro-dealer behavior and farmers noticing the resulting change in seed quality takes some time, rectifying incorrect perceptions of smallholders must have played an important role in increasing their adoption.

8 Conclusion

In this study, we hypothesize that seed quality deteriorates because agro-dealers lack knowledge and/or because asymmetric information results in excessive search costs for farmers and reduced incentives for agro-dealers. Our hypothesized solutions to these problems are a training to inform agro-dealers about correct seed handling and storage practices as well as an information clearinghouse based on crowd-sourced ratings of the quality of seed that agro-dealers sell to farmers. We explore the impact of these solutions on a range of agro-dealer and farmer outcomes with an experimental design that allows for causal attribution and investigation of several underlying mechanisms.

Results show that training agro-dealers is generally ineffective: our training does not change agro-dealer knowledge about proper seed storage and handling, their day-to-day operations, or the seed they sell to farmers. Nor does the training affect farmers' perceptions of seed quality purchased from these agro-dealers or subsequent use of high-yielding seed. The takeaway from these results is that training agro-dealers seems insufficient without additional incentives.

This is where the clearinghouse results come into play. They suggest that if agro-dealers have the right incentives, they may actively seek out the necessary knowledge to improve their operations and stay ahead of their competitors. If agro-dealers are exposed to both incentives and information, they handle and store seed better and attract more business.

Recently, Dar et al. (2023) showed that an information intervention targeted at private input suppliers is effective in changing their behavior and in increasing farmer level adoption, which seems to contradict our null result for the training at first sight. However, their information treatment is very different from ours: instead of training these suppliers in seed handling and storage at the agro-input shop, they give them access to a new seed variety for their own learning, hoping that they will spread this information to their clients who will use it on the farm. Moreover, Dar et al. (2023) find that business incentives and reputational concerns play a key role when agro-dealers share information and give advice, which is in line with our finding that incentives matter.

The information clearinghouse clearly affected the market for maize seed in our study area: sellers and buyers started behaving in line with our theory of change. Agro-dealers reported more business and smallholders reported increased use of quality maize varieties, in turn increasing production outcomes. This effect appears to partly stem from agro-dealers who expanded their service offerings and started signaling quality to customers to outperform their competitors. We find some evidence that this treatment induced farmers to switch between agro-dealers, but most of the impact on farmer outcomes seems to be driven by the clearinghouse improving farmers' opinions of agro-dealers and their products.

The significant impact of the clearinghouse indicates that farmers cannot judge the quality of maize seed at the time of purchase. If the quality of a product cannot be easily assessed at the point of sale, one solution is to make sure customers do not have to, through regulation and quality assurance. Most low- and middle-income countries regulate seed quality in the formal market through codified standards, inspections, and certification systems. However, and particularly in countries that lack institutional capacity to implement and enforce the regulatory framework, the reach of these quality assurance systems is limited. As a result, seed certification provides farmers with a relatively weak and unreliable indication of quality. A decentralized approach that relies on crowd-sourced quality signals such as the information clearinghouse may be more effective.

Furthermore, peer ratings are likely to measure the dimensions of seed quality that matter most to smallholders. While it is possible to objectively measure seed quality (by sending mystery shoppers, followed by DNA fingerprinting) or agro-dealer practices (by sending objective inspectors incognito), it is plausible that farmers are not concerned about genetic purity (indicating whether the seed embodies the genetic characteristics of a specific variety) but mainly care about seed performance (for example, germination rate, vigor, and yield). The opinion of peers who are familiar with the heterogeneous conditions farmers face, may be more useful and trustworthy for smallholders than the judgment of an inspector or DNA test.

A key assumption underlying the clearinghouse mechanisms is that, while individual farmers cannot assess the quality of seed at the time of purchase, collective experience does provide useful information. This is because farmers can learn from experience and use this information when making decisions in subsequent seasons. Empirically, however, farmers may have difficulties drawing a causal link between seed quality, on the one hand, and plant emergence, growth, and harvest, on the other hand, given the extensive set of confounding variables at play (rainfall, soil quality, pest and disease pressure, inputs, management, and plant genetics), the complexity of genotype-by-environment-by-management interactions, and the stochastic nature of many of these variables. In addition, Bayesian learning takes time, and opportunities to learn are limited, despite Uganda having two agricultural seasons. This partly explains the rich body of research on the role of peer effects in technology adoption: combining own experience with the experience of others in a similar location is therefore likely to provide a good signal about seed quality (Conley and Udry, 2010; Bandiera and Rasul, 2006; Foster and Rosenzweig, 1995). A clearinghouse that relies on peer ratings is expected to increase data points that farmers can use when making adoption decisions.

While the complexity of real-world conditions and the intricate dynamics involved necessitate comprehensive, multifaceted approaches, it is challenging to isolate the specific components of the intervention that drive the observed outcomes. The clearinghouse treatment targets the interaction between buyers and sellers and makes information available to all partners. Future research could differentiate between the actors receiving the rating information to determine whether the impact is primarily driven by the information provided to smallholder farmers or to agro-dealers.

Finally, while the crowd-sourced information clearinghouse tested in this study may also be feasible at scale, the idea cannot not be approached naively. There is considerable controversy surrounding the credibility of reviewing platforms and the ability of sellers on these platforms to improve their ratings with payments to customers, automated bot reviews, and other strategic practices. There are also more practical considerations, such as how long ratings should remain valid, or how to deal with sellers who receive high ratings on one set of attributes—seed quality, in this case—but perform poorly in other categories, for example, by engaging in unfair labor practices, engaging in anti-competitive behavior, promoting environmentally hazardous products, or discriminating against certain types of customers. On the other hand, rating farmers themselves may exhibit bias against certain groups of agro-dealers, such as female sellers or those from ethnic minorities, rating them less favorably (De, Miehe, and Van Campenhout, 2024). Rating platforms could potentially amplify these practices and biases rather than address them. While this paper provides both proof of concept and an empirical test of theoretical predictions regarding the relationship between observable product quality and buyer and seller behavior in a market characterized by asymmetric information, further piloting and testing is needed at increasingly larger scales to explore additional hypotheses about market performance, supply and demand responses, and productivity, welfare, and resilience outcomes.

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A Appendix

A.1 Details about rating computations

What to do if a treated agro-dealer does not receive a single rating? If a shop in a treated catchment area is not rated by a single farmer because, for example, no farmer in our sample knows him or her, we could fill in the catchment area mean as his or her rating. However, this is not as innocent as it seems because it is likely that the lack of ratings is not random. Poor quality agro-dealers have less customers, so their likelihood to get rated is lower. Giving them average catchment area ratings inflates the ratings of these low quality agro-dealers. Instead, we simply told farmers that we do not have information about this shop (implicitly informing them that it exists). 16 of 193 treated agro-dealers were not rated by a single farmer in the first round.

Should more ratings lead to better ratings? Some agro-dealers were not rated by any smallholder in the first round, while others were rated by up to 22 smallholders. If agro-dealer A is rated by ten farmers and gets rating 3.5 and agro-dealer B is rated by one farmer and gets rating 3.6, we treat agro-dealer B as the better agro-dealer. Even though receiving many (few) ratings can be related to good (poor) quality (the lack of ratings could be nonrandom, see previous paragraph), there could be other reasons why agro-dealers are rated by many (few) farmers. Furthermore, giving higher ratings to better-known agro-dealers could harm new agro-dealers entering the market and agro-dealers who are discriminated, for example, due to their gender. Also on TripAdvisor, having more reviews than a rival hotel does not lead to a better rating.

Should ratings depend on catchment area agro-dealer performance? The following examples show that ratings should not depend on catchment area averages. In an area with poor quality agro-dealers in which one agro-dealer is a bit better than the rest but still poor, we do not want this agro-dealer to be rated well (that is, expose farmers to poor quality agro-dealers). Similarly, in an area with good agro-dealers in which one agro-dealer is a bit worse than the rest but still good, we do not want this agro-dealer to be rated poorly (which would be unfair towards him or her). On the other hand, less than 9% of agro-dealers received a rating below three out of five, so we would throw away valuable data if we would only disseminate good scores without any variation. Therefore, we take the distribution of ratings into account by using quintiles. Consequently, less agro-dealers receive rating four or five, more agro-dealers receive rating one or two. This could strengthen the effect of the treatment on agro-dealer effort. If agro-dealers get ratings one or two instead of four or five, they could feel more inclined to improve their scores. Consequently, the effect on seed quality itself could be larger. However, the clearinghouse should also have a signaling effect, which might be weaker if more agro-dealers are rated one or two instead of four or five (dealers would seem to be of worse quality to farmers). Therefore, we chose words with a positive connotation as the quintile names for rating dissemination. As most agro-dealers received a good or very good rating before taking the distribution into account, we ensure that even a two is still communicated as “good” to farmers to not weaken the signaling effect. That is why the first quintile is translated to “okay” and gets one star, the second one is named “good” and receives two stars, the third quintile is “very good” and gets three stars, the fourth and fifth quintiles are “excellent” and awarded with four and five stars. This way of considering the distribution of the original ratings when choosing the names also helps us to disseminate ratings as truthfully, purely, and as closely to reality as possible.

Are female agro-dealers rated worse than male agro-dealers? Because we found significant differences between the ratings of female (41% of agro-dealers) and male agro-dealers (59% of agro-dealers) after controlling for some potentially confounding variables like education and for several indications of quality, we have no reason to believe that these differences in perception can be explained by differences in real quality. Instead, it is likely that women are perceived to be worse due to discrimination (De, Miehe, and Van Campenhout, 2024), so we adjusted the ratings of female agro-dealers accordingly to prevent any harm from our intervention. We regressed all seed quality attributes on the gender dummy and added the resulting coefficients to the initial ratings of female agro-dealers.

A.2 Differential attrition tests

Table A1: Differential attrition tests - Agro-dealer

	baseline mean	*midline* attrited	*midline* belongs to CH control	*midline* attrited and CH control	*endline* attrited	*endline* belongs to CH control	*endline* attrited and CH control
Respondent's age in years	32.43	-2.50	2.68^{+}	-1.29	-5.59**	1.59	5.45^{+}
	(11.49)	(2.25)	(1.40)	(3.04)	(1.27)	(1.40)	(3.04)
Resp. is male	0.59	-0.17	0.05	-0.12	-0.34**	-0.02	0.28^{+}
	(0.14)	(0.06)	(0.17)	(0.49)	(0.10)	(0.06)	(0.14)
Resp. finished primary education	0.92	0.01	0.01	-0.02	0.04	0.02	-0.04
	(0.27)	(0.08)	(0.04)	(0.10)	(0.05)	(0.04)	(0.08)
Resp. owns shop	0.55	-0.15	-0.01	0.01	-0.05	-0.05	0.14
	(0.50)	(0.17)	(0.06)	(0.20)	(0.16)	(0.07)	(0.20)
Resp. received training on maize seed handling	0.53	0.14	-0.11	-0.18	0.10	-0.09	-0.19
	(0.50)	(0.11)	(0.07)	(0.16)	(0.10)	(0.07)	(0.15)
Resp. knows how to store seed after repackaging	0.27	0.13	-0.08	-0.10	0.03	-0.09	0.03
	(0.44)	(0.17)	(0.06)	(0.19)	(0.12)	(0.06)	(0.15)
Dealer's distance to nearest tarmac road in km	6.56	-5.37**	1.68	2.63	-3.38^{+}	1.67	0.92
	(10.39)	(1.37)	(2.33)	(2.63)	(1.74)	(2.35)	(2.93)
Dealer only sells farm inputs	0.74	0.11	0.00	-0.18	0.23**	0.01	-0.27*
	(0.44)	(0.10)	(0.07)	(0.14)	(0.07)	(0.07)	(0.12)
Years since dealer establishment	5.34	-1.93	0.07	-0.35	-2.99*	-0.08	0.60
	(6.30)	(1.26)	(0.81)	(1.78)	(0.96)	(0.82)	(1.51)
Number of customers per day	41.49	-7.99	-5.02	-5.48	-8.05	-5.35	-4.79
	(46.49)	(8.66)	(7.50)	(10.59)	(7.01)	(7.73)	(9.53)
Quantity of maize seed sold in kg	695.50	234.18	-144.71	-847.11	125.10	-88.44	-551.67
	(1497.18)	(833.31)	(376.10)	(875.12)	(459.81)	(228.49)	(483.08)
Maize seed lost/wasted last season in kg	3.50	2.73	-2.22	-3.06	3.91	-1.68	-5.89
	(18.65)	(8.06)	(2.35)	(8.16)	(9.08)	(2.59)	(9.21)
Dealer has problem with pests	0.65	0.16	0.08	-0.36*	-0.02	0.04	-0.08
	(0.48)	(0.11)	(0.06)	(0.17)	(0.09)	(0.06)	(0.14)
Dealer stores maize seed in open containers	0.16	-0.05	-0.09^{+}	0.09	-0.05	-0.09^{+}	0.09
	(0.36)	(0.10)	(0.05)	(0.12)	(0.10)	(0.05)	(0.12)
Dealer received seed related customer complaint	0.64	-0.03	-0.04	-0.14	-0.11	-0.07	0.05
	(0.48)	(0.12)	(0.05)	(0.17)	(0.12)	(0.06)	(0.16)
Moisture in bag of maize seed in %	13.56	-0.42	0.10	0.27	-0.45	0.10	0.48
	(1.44)	(0.52)	(0.27)	(0.66)	(0.31)	(0.26)	(0.56)

Note: Column (1) reports sample means at baseline and standard deviations below; columns (2) and (5) report differences between agro-dealers who attrited and those who did not, and standard errors below; columns (3) and (6) report differences between clearinghouse control and treatment agro-dealers, and standard errors below; columns (4) and (7) report differences between agro-dealers who attrited *and* belong to the clearinghouse control group and those who do not, and standard errors below; all standard errors are clustered at the level of randomization; **, *, and + denote significance at the 1%, 5%, and 10% levels.

A.3 Outcome variables and results as they were pre-registered

Table A2: Effects on primary agro-dealer outcomes

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Quantity of maize seed sold in kg§†	695.503	-0.092	0.284	292	-0.499^{+}	0.239	286
	(1497.183)	(0.220)	(0.227)		(0.250)	(0.253)	
Sales price of maize seed in UGX/kg	4273.897	-192.784^{+}	99.272	275	-33.867	145.861	264
	(955.073)	(114.934)	(113.292)		(143.152)	(138.816)	
Revenue from maize seed in mln UGX§†	2.890	-0.069	0.185^{+}	292	-0.227^{+}	0.143	286
	(6.286)	(0.104)	(0.108)		(0.118)	(0.118)	
Number of maize seed customers per day§†	19.764	-0.056	0.127	294	-0.190	0.310**	288
	(20.689)	(0.098)	(0.101)		(0.116)	(0.112)	
Moisture in randomly selected seed bag in %	13.563	0.017	-0.122	175	-0.041	-0.220	261
	(1.442)	(0.142)	(0.144)		(0.198)	(0.197)	
Index of capital-intensive seed handling practices^{1†}	0.000	-0.019	0.000	270	-0.087	0.070	265
	(0.508)	(0.063)	(0.072)		(0.092)	(0.081)	
Index of labor-intensive seed handling practices^{2†}	0.010	0.058	0.099	285	0.083	0.074	274
	(0.484)	(0.070)	(0.065)		(0.067)	(0.068)	
Index of all seed handling practices^{3}	0.009	0.042	0.052	251	0.021	0.083	248
	(0.382)	(0.051)	(0.053)		(0.063)	(0.059)	
Index of dealer's efforts and services^{4†}	0.000	-0.063	0.066	243	-0.031	0.086^{+}	297
	(0.454)	(0.062)	(0.060)		(0.051)	(0.048)	
Index of shop's maize seed ratings by farmers^{5}	-0.018				0.020	0.122	327
	(0.595)				(0.102)	(0.101)	
Overall index	0.007	-0.004	0.214^{+}	215	-0.058	0.239*	258
	(0.591)	(0.130)	(0.121)		(0.128)	(0.117)	
Max. number of obs. for dealer survey outcomes				306			297

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

§Due to the skewness of this variable, the regression was run after an inverse hyperbolic sine transformation. Coefficient estimates can therefore be interpreted as percentage changes. The baseline mean column shows the untransformed variable.

[1]The index of capital-intensive seed handling and storage practices contains 6 variables: whether roof is leak-proof, whether roof is insulated, whether walls are insulated, whether shop is ventilated, whether any official certificate is displayed, whether expired seed is handled correctly.

[2]The index of labor-intensive seed handling and storage practices contains 6 variables: whether seed is stored in dedicated area, whether shop has no pest problem, whether seed is stored in correct lighting, whether seed is stored on correct surface, whether seed is not stored in open containers, cleanness and professionality rating by enumerator.

[3]The index of all seed handling and storage practices contains 12 variables: the ones included in the index of capital-intensive practices and the ones included in the index of labor-intensive practices.

[4]The index of dealer's efforts and services contains 7 variables: whether shop offers explanations, complementary input recommendations, extension/training, discounts for larger quantities, credit, did not receive seed related customer complaint, accepts mobile money.

[5]The index of shop's maize seed ratings by farmers contains 6 ratings: general quality, yield, drought tolerance, pest/disease tolerance, time of maturity, germination. Ratings are aggregated at shop level (one shop is rated by multiple farmers), then the index is computed.

Table A1: Effects on secondary agro-dealer outcomes: Indices

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Index of dealer's motivation and satisfaction[1]	0.000	0.033	0.000	306	-0.109	-0.076	286
	(0.674)	(0.082)	(0.085)		(0.082)	(0.086)	
Index of dealer's self-ratings[2]	0.000	-0.068	-0.002	306	-0.132	0.080	297
	(0.651)	(0.084)	(0.079)		(0.086)	(0.079)	
Index of dealer's efforts and services according to farmers[3]	-0.027	-0.151*	0.301**	259	0.006	0.086	271
	(0.583)	(0.074)	(0.069)		(0.092)	(0.084)	
Index of dealer's knowledge about seed storage[4]	0.000	0.091	0.115	306	0.030	0.124*	297
	(0.482)	(0.076)	(0.075)		(0.053)	(0.055)	
Index of dealer's knowledge about seed[5]	0.000	0.102	0.065	306	-0.009	-0.007	297
	(0.533)	(0.072)	(0.070)		(0.080)	(0.078)	
Max. number of obs.				306			297

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

[1]The index of dealer's motivation and satisfaction contains 3 variables: whether dealers see themselves working as agro-dealers in future, would recommend working as dealers, how happy dealers feel when they come to work. We report the mean and standard deviation at midline because these variables were not collected at baseline.

[2]The index of dealer's self-ratings contains 5 ratings: location, price, product quality, stock, reputation.

[3]The index of dealer's efforts and services according to farmers contains 7 variables: whether shop offers refund/insurance, credit, training/advice, delivery, after-sales service, accepts different payment methods, sells small quantities. The answers are aggregated at dealer level, then the index is computed.

[4]The index of dealer's knowledge about seed storage contains 5 variables: whether dealer knows how long seed can be carried over, how seed should be stored after repackaging, what the min. distance between floor and seed is, how seed should be stored in storeroom, whether seed should be repackaged.

[5]The index of dealer's knowledge about seed contains 4 variables: whether dealer knows which seed variety to recommend if farmer complains about poor soil, if farmer complains about little rain, if farmer is late for planting, what to tell clients about yield benefits of hybrid seed.

Table A2: Effects on primary farmer outcomes

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Farmer planted high-yielding maize seed on any plot†	0.492	-0.021	0.035^{+}	3206	-0.009	0.042*	3282
	(0.500)	(0.020)	(0.020)		(0.020)	(0.020)	
Farmer bought maize seed at agro-input shop for any plot†	0.325	-0.014	0.059**	3145	0.004	0.031	3225
	(0.468)	(0.021)	(0.021)		(0.019)	(0.020)	
Amount of this seed farmer bought at agro-input shop in kg	9.519	0.512	-0.105	599	0.457	0.378	621
	(6.920)	(0.348)	(0.358)		(0.419)	(0.431)	
Index of farmer's maize seed ratings of agro-dealers within catchment area[1]	0.000				0.021	0.092^{+}	1664
	(0.637)				(0.054)	(0.054)	
Index of farmer's general ratings of agro-dealers within catchment area[2]	0.000				-0.026	-0.005	1706
	(0.657)				(0.043)	(0.042)	
Index of services of agro-dealers within catchment area according to farmers[3]	-0.037	-0.138^{+}	0.161*	312	0.034	0.131^{+}	320
	(0.609)	(0.073)	(0.067)		(0.081)	(0.077)	
Farmer switched to different agro-input shop[4]†	0.168	-0.013	0.042**	3407	-0.024	0.026^{+}	3441
	(0.374)	(0.014)	(0.014)		(0.015)	(0.015)	
Index of farmer's practices on randomly selected plot[5]†	0.008	0.011	-0.026	2929	0.001	0.016	3053
	(0.400)	(0.019)	(0.019)		(0.021)	(0.021)	
Farmer thinks maize seed at agro-dealers is adulterated	0.685	-0.033	-0.041	2113	-0.041	0.020	2167
	(0.465)	(0.027)	(0.027)		(0.028)	(0.028)	
Farmer planted land race maize seed on randomly selected plot†	0.448	0.015	-0.013	2954	0.009	-0.024	3047
	(0.497)	(0.021)	(0.020)		(0.022)	(0.022)	
Overall index[6]	0.009	0.008	0.017	2933	-0.023	0.063^{+}	3083
	(0.698)	(0.033)	(0.034)		(0.034)	(0.034)	
Max. number of obs.				3407			3441

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

[1]The index of farmer's maize seed ratings contains 6 ratings: general quality, yield, drought tolerance, pest/disease tolerance, time of maturity, germination. The ratings are aggregated at farmer level (one farmer rates multiple agro-dealers), then this index is computed.

[2]The index of farmer's general ratings contains 6 ratings: general quality, location, price, product quality, stock, reputation. The ratings are aggregated at farmer level (one farmer rates multiple agro-dealers), then this index is computed.

[3]The index of services of agro-dealers within catchment area contains 7 variables: whether shop offers refund/insurance, credit, training/advice, delivery, after-sales service, accepts different payment methods, sells small quantities. The answers are aggregated at shop level, then the index is computed at farmer level. Only 320 farmers answered all 7 questions for at least one shop within the catchment area at baseline and at endline.

[4]We report the mean and standard deviation at midline because this variable was not collected at baseline.

[5]The index of farmer's practices contains 10 variables: whether farmer spaced seed correctly, sowed correct number of seeds/hill, applied organic manure, DAP/NPK, Urea, pesticides/herbicides/fungicides, weeded sufficiently, weeded at correct time, planted at correct time, re-sowed.

[6]We report the mean and standard deviation at midline because not all variables in this index were collected at baseline.

Table A3: Effects on secondary farmer outcomes: Adoption on randomly selected maize plot

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Farmer planted hybrid seed†	0.264	0.002	0.009	2654	-0.023	0.032	2700
	(0.441)	(0.022)	(0.022)		(0.023)	(0.023)	
Farmer planted OPV†	0.260	-0.017	0.002	2654	0.010	-0.007	2700
	(0.439)	(0.022)	(0.022)		(0.020)	(0.021)	
Farmer planted farmer-saved seed†	0.579	0.020	-0.042^{+}	3153	-0.009	-0.016	3240
	(0.494)	(0.022)	(0.022)		(0.020)	(0.020)	
Farmer planted seed bought at agro-input shop†	0.330	-0.010	0.047^{*}	3153	0.012	0.036^{+}	3240
	(0.470)	(0.022)	(0.022)		(0.019)	(0.019)	
Farmer planted hybrid variety or OPV[1]	0.432	-0.019	0.035	2954	0.009	0.030	3047
	(0.495)	(0.023)	(0.023)		(0.023)	(0.023)	
Overall index	-0.003	0.000	0.002	2867	-0.010	0.026	2963
	(0.553)	(0.024)	(0.024)		(0.025)	(0.025)	
Max. number of obs.				3407			3441

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.
[1]For this variable, only seed which was not farmer-saved counted as hybrid seed and only seed which was not recycled too often counted as OPV.

A.4 Effects on seed quality

To assess the effects of the agro-dealer training and the information clearinghouse on the quality of seed sold by agro-dealers, we tried to purchase a bag of seed at each agro-dealer and inspected it on a number of attributes. First, we measured the moisture content of the seed. In Table A4, we see that the clearinghouse treatment reduced moisture as expected, but the parameter is estimated imprecisely, perhaps due to the smaller data set as we were not able to source seed from all agro-dealers and the comparisons were only made for agro-dealers from which the enumerator was able to buy a bag of maize seed at midline or endline. We further look at the integrity of the package and whether it shows important information such as the packaging date and lot number. Given that seed quality decreases with shelf-life, we also look at the days since the packaging date or, if the bag does not show the packaging date, the days since the expiry date minus 6 months. We do not find that the information clearinghouse treatment or the agro-dealer training affected quality proxies of the seed that agro-dealers sell. However, because our proxies of seed quality are far from perfect and we rely on a smaller sample, we cannot safely conclude that the treatments did not affect seed quality.[30]

[30] Assessing seed quality is not only challenging for farmers, but also for researchers. Even though investigating moisture is an attempt to test the quality of seeds in a quantitative and objective way, this variable is one-dimensional and not perfectly correlated with seed performance. Additional ways to capture seed quality include lab testing to measure purity as the rate of extraneous, non-seed material in the bag, germination using a germination chamber, grow-out tests for genetic purity using morphological analysis, and DNA fingerprinting to test for genetic purity using single nucleotide polymorphisms tests.

Table A4: Effects on agro-dealer outcomes: Bag of maize seed

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Moisture in %†	13.564	0.017	-0.122	175	-0.041	-0.220	261
	(1.482)	(0.142)	(0.144)		(0.198)	(0.197)	
Moisture exceeds recommended level (13%)	0.492	-0.046	-0.011	175	-0.062	-0.102	261
	(0.501)	(0.082)	(0.081)		(0.071)	(0.069)	
Bag shows packaging date†	0.689	0.053	0.050	179	-0.091	0.035	265
	(0.464)	(0.069)	(0.072)		(0.063)	(0.064)	
Shelf-life in days^{1†}	60.951	-18.930	-8.272	164	13.091	6.352	240
	(40.960)	(22.091)	(20.869)		(8.243)	(8.289)	
Seed is in original undamaged bag†	0.940	0.025	0.002	179	0.006	0.051	265
	(0.238)	(0.044)	(0.046)		(0.053)	(0.055)	
Bag shows lot number†	0.508	0.025	-0.001	179	-0.138*	0.027	265
	(0.501)	(0.106)	(0.107)		(0.062)	(0.064)	
Overall index	0.065	0.083	0.108	160	-0.067	0.108	236
	(0.364)	(0.103)	(0.103)		(0.094)	(0.090)	
Max. number of obs.^{2}				179			265

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.

[1]Days since the packaging date or, if the bag does not show the packaging date, days since the expiry date minus 6 months.

[2]The comparisons were only made for agro-dealers where the enumerator was able to buy a bag of maize seed at mid- or endline. Also, we do not control for the baseline values of the outcome variables in the entire table because only 144 of the 179 dealers who had seed at midline also had seed at baseline and only 183 of the 265 dealers who had seed at endline also had seed at baseline, so that controlling for baseline values would reduce the sample sizes drastically.

A.5 Questions to measure agro-dealer knowledge

Agro-dealer knowledge about seed storage

1. How long can seed be carried over before losing viability?
   (a) Seed can be carried over into the next seasons as you can store seed for twelve months.
   (b) Seed cannot be carried over into the next seasons as six months is the longest seed can be stored.
   (c) This depends on the seed: hybrids cannot be carried over, OPVs can be carried over for five seasons.
   (d) I don't know.
2. How should seed best be stored after repackaging?
   (a) Airtight in polyethylene bags.
   (b) In paper bags or perforated polyethylene bags.
   (c) In a sealed tin/plastic container.
   (d) I don't know.
3. What is the minimum recommended distance between the floor and where seed is stored?
   (a) 0 inches, seed should be stored directly on the floor for maximum stability.
   (b) Minimum two inches from the floor.
   (c) Minimum six inches from the floor.
   (d) I don't know.
4. How should seed ideally be stored in your store room?
   (a) In sealed cardboard boxes.
   (b) Stacked on pallets.
   (c) Arranged on shelves with sufficient space between packets.
   (d) I don't know.
5. Which statement do you agree most with?
   (a) You should repackage all your seed to visually verify that you are selling good quality seed.
   (b) You should repackages all your seed so you can sell more to small farmers.
   (c) You should avoid repackaging your seed as much as possible.
   (d) I don't know.

Agro-dealer knowledge about seed

1. If a farmer complains about poor soil, which maize variety do you recommend?
   - (a) Longe 5.
   - (b) Bazooka.
   - (c) Longe 10H.
   - (d) I don't know.
2. What do you tell clients who inquire about the yield benefits of hybrid seeds?
   - (a) Hybrid seeds double maize yields (increasing yield from about 4 to 8 bags/acre).
   - (b) Hybrid seeds triple maize yields (increasing yield from about 4 to 12 bags/acre).
   - (c) Hybrid seeds increase yields tenfold (increasing yield from about 4 to 40 bags/acre).
   - (d) I don't know.
3. If a farmer misses the rains or lives in an area that receives little rain, which maize variety do you recommend?
   - (a) Longe 10H.
   - (b) Longe 7H.
   - (c) Wema.
   - (d) I don't know.
4. If a farmer is late for planting in the short season and needs a fast maturing variety, which maize variety do you recommend?
   - (a) Bazooka.
   - (b) Longe 10H.
   - (c) Myezi mitatu (mm3).
   - (d) I don't know.

A.6 Effects on agro-dealer knowledge - Individual variables

Table A7: Effects on agro-dealer outcomes: Knowledge (individual variables)

	baseline	*midline*			*endline*		
	mean	training	CH	obs.	training	CH	obs.
Dealer knows...							
...how long seed can be carried over†	0.336	0.085	0.080	306	0.039	0.089	297
	(0.473)	(0.078)	(0.076)		(0.062)	(0.061)	
...how seed should be stored after repackaging†	0.270	0.067	0.055	306	-0.075	-0.018	297
	(0.445)	(0.065)	(0.064)		(0.053)	(0.055)	
...what the min. distance between floor and seed is†	0.526	0.079	0.078	306	0.080	0.056	297
	(0.500)	(0.060)	(0.061)		(0.061)	(0.062)	
...how seed should be stored in storeroom†	0.552	0.007	-0.007	306	0.061	0.071	297
	(0.498)	(0.058)	(0.057)		(0.054)	(0.055)	
...whether seed should be repackaged†	0.638	0.008	0.080	306	0.023	0.119	297
	(0.481)	(0.064)	(0.066)		(0.069)	(0.073)	
Index of dealer knowledge about seed storage	0.000	0.091	0.115	306	0.030	0.124*	297
	(0.482)	(0.076)	(0.075)		(0.053)	(0.055)	
Dealer knows...							
...which variety to recommend if farmer complains about poor soil†	0.193	0.050	0.049	306	0.002	-0.004	297
	(0.395)	(0.048)	(0.049)		(0.054)	(0.054)	
...which variety to recommend if farmer complains about little rain†	0.052	-0.014	-0.004	306	-0.058	0.028	297
	(0.222)	(0.040)	(0.040)		(0.049)	(0.045)	
...which variety to recommend if farmer is late for planting†	0.218	0.132^{+}	0.052	306	0.001	0.038	297
	(0.414)	(0.073)	(0.068)		(0.082)	(0.077)	
...what to tell clients about yield benefits of hybrid seed†	0.445	0.001	0.023	306	0.054	-0.082	297
	(0.498)	(0.062)	(0.061)		(0.059)	(0.060)	
Index of dealer knowledge about seed	0.000	0.102	0.065	306	-0.009	-0.007	297
	(0.533)	(0.072)	(0.070)		(0.080)	(0.078)	
Max. number of obs.				306			297

Note: Column (1) reports baseline means and standard deviations below; columns (2), (3), (5), and (6) report differences between treatment and control groups and standard errors below; they are clustered at the level of randomization; columns (4) and (7) report the number of observations; **, *, and + denote significance at the 1%, 5%, and 10% levels; † indicates that the variable is included in the overall index; larger indices indicate more desirable outcomes.