Leveraging information and communication technology (ICT) to provide agricultural advice to smallholder farmers

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Abstract

Agricultural advisory services generally rely on interpersonal knowledge transfer, involving agricultural extension officers visiting farmers individually or in groups. This approach is not always cost-effective and has often proved hard to bring to scale. Information and communication technologies (ICT) have been advanced as a promising way to overcome many of the problems that plague the traditional extension model. We test the effectiveness of three ICT-mediated approaches to deliver agricultural extension information among maize farmers in eastern Uganda. First, we investigate the effectiveness of video as means to transfer knowledge, increase technology adoption, increase productivity and improve well-being. Second, we quantify the additional impact of augmenting video with interactive voice response (IVR) technology—a more demand-driven approach to information provision. Third, we complement the IVR technology with time-sensitive short message service (SMS) messages, reminding farmers about key agronomic practices and technologies, and encouraging

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them to use the IVR service. We find that video is an effective technology to provide agricultural extension information: Households that were shown a short engaging video on how the become a better maize farmer did significantly better on a knowledge test, applied more of the recommended practices, and used inputs better than households that did not see this video. They also reported maize yields that were about 10 percent higher. Additional effects from IVR and SMS technologies are limited.

Introduction

With new possibilities offered by information and communications technology (ICT), an abundance of pilot projects and commercial products have entered the market with a focus on revitalizing agricultural extension in developing countries. However, a growing body of evidence suggests that not all ICT-mediated extension approaches are equally effective in achieving outcomes such as increased knowledge and awareness, higher rates of technology adoption, better crop yields, and eventually improvements in household welfare. This may be because, as has been found in information campaigns more generally, seemingly small design attributes—the way information is delivered, who delivers the information, and who was targeted—can significantly influence these outcomes.

This paper investigates the effectiveness of an ICT-enabled extension approach designed to provide information about improved maize cultivation practices to smallholder farmers in Uganda. We consider the specific technolgy through which the information is delivered to the farmer, and differentiate between (i) short audiovisual messages viewed on tablet computers that provide detailed information on improved maize cultivation; (ii) interactive voice response (IVR) systems that farmers call into if the need for additional information arises; and (iii) short message service (SMS) that nudge farmers at particular points in time about key farming practices they should apply and encourages them to seek more information through the IVR. The outcomes used to assess the relative effectiveness of these different ICTs include increases in knowledge about improved maize cultivation and changes in household-level indicators such as the use of improved inputs, technologies, and practices. We also look at the effect of the three different extension models on farm production outcomes, maize disposal, and household level welfare.

We draw on a field experiment in which farmers are randomly assigned to a group that received a particular combination of ICT-mediated information interventions, and are then compared to a group that did not receive that particular information intervention (de Janvry, Sadoulet, and Suri, 2017). We work with almost 4,000 farm households sampled from the population of households cultivating maize across five districts of eastern Uganda. The first intervention takes the form of a short video that explains simple yet effective ways to increase maize productivity and profitability, such as recommended practices on row spacing and seed rate, the importance of quality seed, optimal soil fertility management, and farm budget management. To test the overall effectiveness of the information provided through the video medium, we compare outcomes of farmers who were shown the informational video to outcomes of farmers who were exposed to a placebo video. In addition, we provide supplementary access to an IVR system to about two-thirds of the sampled households who were shown the informational video and, within that group, we send about half of the sampled households a series of eight follow-up SMS messages at strategic points in time.

We find that providing information to farmers through short video messages significantly increased their knowledge about modern inputs, improved technologies, and recommended practices. In addition, farmers who were shown the video were also more likely to adopt a range of inputs, technologies, and practices that were promoted in the videos. We also find clear effects on production, with maize yields 10 percent higher than in control households. However, these results do not translate into greater well-being. We also find that the IVR generated no additional impact on knowledge, nor did it have a strong influence on technology adoption: we only find a positive effect of IVR on the uptake of hybrid seed. While the SMS reminders did increase the likelihood that farmers used the IVR service, there were no additional effects on other outcomes.

The remainder of the paper is organized as follows. The next section lays out the main research questions and explains how the study fits into the broader literature. Section 3 explains the experimental design and corresponding sampling frame. Section 4 describes the study site and context, while Section 5 describes the interventions used as the treatments in the experiment. We then turn to the results in Section 6 with a discussion of baseline characteristics and sample balance. This is followed by analysis of the impact of the three technologies tested, with subsections for impact on knowledge, practices adopted and inputs used, production, disposal, and welfare. A final section provides concluding remarks and recommendations for future program and research investments in ICT-enabled agricultural extension and advisory services.

Research Aim

The primary focus of this study is to test alternative ways in which information is provided to farmers through ICT channels for improving the effectiveness of agricultural extension services. Doing so, we aim to contribute to the literature on how ICTs can increase the adoption of modern inputs and improved crop management practices among smallholder farmers—a topic that has received considerable attention in recent years but has lacked sufficient evidence on which approaches work and for whom (Nakasone and Torero, 2016). The role of ICTs in improving access to information on crop management—as compared to improving access to market and price information—is a particularly challenging topic. Information of this kind is often non-excludable and non-rival in nature, requiring government intervention when it is under-supplied by the private sector. Government intervention in this area typically takes the form of information campaigns, extension programs, and advisory services, many of which have been met with mixed success (Feder et al., 2010; Birner et al., 2009; Haug, 1999; Davis, 2008). These ambiguous outcomes are often associated with specificities of the technology, practice, or principle being promoted; the agroecological and socioeconomic context in which it is being promoted; and other confounding factors that may be poorly understood or too costly to address in program design and implementation. For example, the fact that many of the potential beneficiaries of extension services live in remote areas with limited transportation infrastructure often makes Training and Visit extension too costly. Poor wages for public extension workers impacts motivation and accountability. As a result, ICT applications to extension such as SMS reminders, purpose-built smartphone apps, IVR systems and hotlines, portable tablets and projectors, and other hardware and software solutions have received considerable attention in recent years as a means of addressing many of these issues.

Several studies have reported positive impacts of ICTs applied to extension services. For example, Cole and Fernando (2016) found that the introduction of a toll-free hotline, through which farmers can ask questions to agricultural experts significantly increased cumin and cotton yields among farmers in Gujarat, India. Fu and Akter (2016) found that a multi-media mobile phone-based product linked to expert advisory services increased farmers' awareness and knowledge about specific solutions to their production constraints in Madhya Pradesh, India. Maredia et al. (2017), on the other hand, found that while mobile phone-based animated videos shown to farmers in Burkina Faso induced learning and understanding, it was no more effective in encouraging adoption than conventional approaches to information provision. In Uganda—the site of our study—Grameen Foundation had some success using smartphones to provide agriculture-related information to farmers through ICT-empowered community knowledge workers (Van Campenhout, 2017).

Our study compares three technologies, each with their own characteristics. Video is a supply-driven intervention through which information is made available at only a limited number of occasion (we showed the video only twice) and at moments that are decided upon by the supplier of the information (we showed the video before the maize planting season and early during planting). The strength of video is that it can combine audio and visual information in an attractive way that is recognizable to the farmer. For instance, we use local farmers as it has been found that information may be more effective if it is brought by someone one can identify with. We presume that such a supply driven approach may be particularly effective in the dissemination of new technologies and practices.

Demand-driven extension approaches such as hotlines or IVRs assume that farmers can identify their information needs and are capable of actively search for additional information[1]. One of the main advantages of this approach is that it is always accessible and so farmers can access the information whenever the need arises. It is also less expensive than video, since one does not have to physically meet with farmers to transfer the information[2]. Uganda has some experience with demand-driven extension, as its National Agricultural Advisory Services (NAADS) was build on a consulting business model (Benin et al., 2011). This type of extension may be more effective

[1]A hotline is a phone number that can be called by a farmer and questions can be asked to an expert. In an IVR, a farmer calls a number and navigates through a menu to select a topic. The farmer then gets to listen to a pre-recorded message.

[2]In fact, it may also be possible to simply stream video to mobile phones of farmers. That said, this would likely be more expensive than IVR since more data need to be transferred.

when farmers have to deal with unanticipated shocks such pests or adverse weather conditions (Cole and Fernando, 2016).

Finally, SMS reminders are also supply-driven, but instead of offering all the information at only one point in time, they are designed to remind farmers on a recurrent basis about important aspects of maize farming. However, SMS messages are short and can not be used to provide new and complex information; in the present study, they are only used to make the information that was provided in the video more salient and to encourage farmers to use the IVR.

More broadly, we contribute to long-standing research efforts that document and measure the adoption and impact of improved agricultural technologies and management practices among smallholder farmers. There are many reasons for the observed low rates of adoption of improved technologies and practices among smallholder farm households, including lack of access to credit and insurance, poorly developed labour markets, and asymmetries of information within markets (Feder, Just, and Zilberman, 1985; Jack, 2013). Our contribution is methodological in nature in recognition of two important points. First, few studies apply sufficiently rigorous methods to address concerns about sample selection bias and causal identification in the study of technical change in developing-country agriculture (De Janvry, Dustan, and Sadoulet, 2010). Second, few studies on ICT-enabled extension are replicated in differing contexts and populations to increase both generalizable findings and nuanced insights on the impact pathways through which ICT operates on farmers' decision-making about technology adoption.

Ctrl	Video		
256	3703		
		IVR	
		2414	
			SMS
			1113

Figure 1: Experimental Design Layout

Experimental Design and Corresponding Sampling Frame

The three technologies are tested with a field experiment[3]. The experiment has four treatment arms and IVR and SMS treatments are incremental. The experimental unit is the household. We have a control group of 256 households that was shown a placebo video. Furthermore, 3,703 households were shown a video. From those 3,703 households that were shown a video, 2,414 also received the IVR number and instructions on how to use it. From those 2,414 households that were shown a video and received the IVR encouragement 1,113 households were also allocated to the SMS treatment. This design, together with the sample size in each treatment category, is illustrated in the top panel of Figure 1.

To evaluate the effectiveness of the different modes of information provision, we start by comparing average household level outcomes among farm households in the control group to average outcomes of farming households that were shown a video. Ex-ante, we expected largest effects between the video group and the control group and power calculations indicated that we only needed about 250 observations in each group[4]. This gives us the average

[3]This study is part of a larger study that also looked at the role of gender in video mediated agricultural extension. The overall study took the form of a 3^3 factorial design (plus a separate pure control group), where one factor corresponds to the technology used and the other two factors varied the gender of the person to whom the video was shown within the household and the gender of the person who provides the information. In this study, we restrict attention the first factor. More information on the overall study can be found in the pre-analysis plan, which is pre-registered and publicly available from the American Economic Association's registry for randomized controlled trials (AEARCTR-0002153).

[4]Power calculations were bases on an elaborate set of comparisons using different out-

treatment effect for the video intervention. To get the additional effect of the IVR treatment, we compare average outcomes of households that were shown a video and received the IVR intervention as well to households that were shown only a video . Finally, the additional effect of the SMS campaign can be estimated by comparing outcomes of household that were shown a video, received IVR information and also received the eight SMS reminders to outcomes of households that are shown a video and received the information about the IVR system, but did not get the SMS reminders.

Context

We conducted the field experiment among maize farmer in Uganda. Maize is widely consumed throughout much of Uganda, yet its value-to-weight ratio is sufficiently high to also make it an important traded commodity. Therefore, efforts to increase maize productivity at the farm-household level are an important dimension of Uganda's strategy to increase food security and reduce poverty through both consumption and income channels. Yet maize yields in Uganda are low when compared to neighbouring countries and global averages. While research station trials conducted in Uganda report potential yields of about 1.6 metric tons per acre (using only improved varieties without fertilizer application), data from the Uganda National Household Survey 2005/06 indicate that average maize yields are much lower at about 618 kg per acre for the main growing season (Fermont and Benson, 2011). Moreover, there is considerable variation in productivity across farmers, with the top 10 percent of farmers achieving yields in excess of 1.1 metric tons per acre. At the same time, the use of modern inputs such as inorganic fertilizer and management practices such as row planting is very low in Uganda. For example, the use of inorganic fertilizer is on average just 2.4 kg of nutrient per acre per year, compared to Kenya (75 kg/ac), Rwanda (70 kg/ac), and Tanzania (15 kg/ac).

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comes to power the complete 3^3 factorial design. We used simulation techniques that allowed us to to sample from actual data on outcome variables (maize yields obtained from Uganda National Household Survey of 2005/06) instead of from a theoretical distribution with an assumed mean and standard deviation. Apart from the sample size in the control group, sample size in other treatment arms are the result of minimal sample size needed to test differences in two other factors of the design. Detailed information on the power calculations can be found in the pre-analysis.

Maize is especially important in eastern Uganda. We sampled from five districts in eastern Uganda known for their maize production: Bugiri, Mayuge, Iganga, Namayingo, and Namutumba. From this, we removed town councils and also two sub-counties that consisted of islands in lake Victoria. We used two-stage cluster sampling to obtain a representative sample of this population. In particular, we first selected parishes randomly and in proportion to the number of villages within each parish. In the selected parishes, all villages were included in the study. Within each village, we then listed all the households, from which we sampled households to be included in the study.

In eastern Uganda, there are two maize cropping seasons. For our study, we concentrated on the second maize-growing season of the year 2017, which ran from approximately August 2017 to January 2018 and is characterized by a shorter period of rainfall than the first maize-growing season. During this second season, the complete cycle from planting to harvest requires 3 to 3.5 months, and farmers tend to cultivate early-maturing but lower yielding maize varieties as a result. Fields are prepared in August, planted in September. Harvesting begins in mid to late December and, at higher elevations, can continue until mid January.

Interventions

The first intervention used in the study was a video that was shown on 10-inch Android tablet computers. Videos were screened by a trained field enumerator who sat with individual farmers. The control group received a placebo treatment, which was a music video of traditional dancing that contained no information related to farming. Videos (treatment or placebo) were screened twice to the households in the sample, once before the time for planting maize (July 2017) and once around planting time (August 2017).

The information contained in the treatment groups' video is expected to positively influence maize yields by encouraging the adoption of several improved technologies and practices which, in turn, are expected to positively affect farm-household income. The topics included in the video script were obtained from qualitative interviews with key informants that were conducted in May 2017, and included maize farmers, value chain actors, maize breeders, extension workers, district agricultural officers, and other government staff and experts.

The main factors affecting maize productivity that were identified by these key informants were related to pests, poor soils, and poor seed quality. The three most important **pests** that affect maize farming are striga (in particular the *Striga hermonihica* variety), maize stalk borer (*Busseola fusca*), and, more recently, fall armyworm (*Spodoptera frugiperda*). We focus on striga management in the videos because it was deemed more immediately problematic to our population of interest than maize stalk borer, and because, at the time this field experiment was conducted, there was no consistent strategy being promoted to address fall armyworm. Striga, also called witchweed, is a parasitic plant that feeds off the roots of maize, leading to severe stunting of the maize plant. Because the nutritional needs of maize are greatest at the early stages of growth, weeding of striga becomes less effective in curbing losses as the season progresses. Striga can reduce production from about 30 percent up to total loss of the crop.

No single method is effective in controlling striga. Progress has been made in developing varieties that are resistant to the herbicide imazapyr and can be supplied with a imazapyr seed coating to contain striga before it can damage the host plant. However, the seeds of this variety on offer in Uganda are expensive at 10,000 Ugandan Shillings (UGX) per kg, while seeds of other common/popular varieties cost between 6,000 and 8,000 UGX/kg, [5] and does poorly under dry conditions and in areas where the rains are short such as in eastern Uganda.[6] Crop rotation with sweet potato or beans can also reduce striga infestation, as can applications of phosphatic fertilizer to make up for the nutrients drained by the parasitic weed. Weeding is also a strategy to control striga, and is most effective in the weed's earliest growth stages, before it establishes itself on the maize plant's root system and before it has a chance to spread via seed dispersal.

Poor soils, exhausted by continuous cultivation with little rotation, is the second main limiting factor. Soils often lack macro-nutrients such as nitrogen (N), phosphorous (P) and potassium (K), and farmers in our study area rarely use organic or inorganic fertilizers in sufficient quantities to ameliorate these deficiencies, either at the planting stage (when diammonium phosphate (DAP) or nitrogen-phosphorous-potassium (NPK) applications

[5] At the time this study was conducted, the official exchange rate was approximately UGX/USD 3,600.

[6] In the near future, it is expected that the same herbicide-resistance trait and seed-coating technology will be released in early-maturing varieties such as Longe 10, which are preferred in eastern Uganda. See https://striga.aatf-africa.org/.

are recommended), or at the vegetative growth stage (when top dressings of nitrogenous fertilizers such as Urea are recommended).

Throughout eastern Uganda, maize farmers mainly rely on **seed saved from harvest**, which represents the third limiting factor identifying by key informants. The reliance on saved (recycled) seeds tends to negate the significant yield advantages conferred by high-yielding maize hybrids, which require that new F1 seed be purchased at the start of each season to realize the gains conferred by heterosis or hybrid vigor. And even where farmers rely on recycled seed from improved open-pollinated varieties (OPVs) that do not require seasonal replacement, the gains from improvement tend to depreciate over three to four seasons, again requiring farmers to purchase new seed at regular intervals. Gains from the improved genetic qualities of both maize hybrids and OPVs can increase yields between 30 and 200 percent, depending on climatic conditions and the complementary use of modern inputs and intensive management practices.

Finally, there are also **crop management practices** that affect yields, but the effects are generally smaller than those related to improved seeds and inorganic fertilizer use. The most important are timely planting, optimal plant spacing, and timely weeding.

Timely planting in eastern Uganda implies that maize should be planted at the onset of the rains. However, many farmers delay planting for several reasons. For instance, they may not be certain that the rainy season has really started. There may also be bottlenecks in land preparation, where poorer farmers are often the last in line for the use of oxen or tractors. Experts estimate that for each day a farmer delays planting, yields are reduced by 1.5 percent.

Optimal plant spacing implies that sowing should be structured so that plants are not too close to each other such that they compete for light and nutrients which, in turn, reduces yields. Plants that are too far from each other means space is wasted, also leading to lower yields. Related is the number of seeds that farmers plant in each hill. Farmers want to be sure of germination and put more than one seed, sometimes up to 5. If they all germinate, there is competition for nutrients and sun, resulting in stunted growth. Usually there is also not enough thinning, or this is done too late when competition has already occurred. One expert told us that standard spacing is 75cm x 60cm with two plants per hill. However, several experts mentioned a new way of plant spacing of 75cm x 30cm with a reduced seed rate of 1 seed per hill which leads to a 35 percent increase in yields.

Timely weeding implies that the first weeding should be done at 18 to 20 days after planting, with a second weeding at two to three weeks after first weeding. From emergence to the “eight-leaf” stage (when the maize is at about knee height), the maize plant is a very poor competitor and unwanted stress such as weed competition must be prevented. A third weeding at the tasseling stage is optional, and depends on observed weed pressure after the second weeding.

Given the above, a significant portion of the videos focuses on providing technical information on seed choice, soil nutrient management (including the promotion of both organic and inorganic fertilizer application), weeding (with particular attention on fighting striga), timely planting, and plant spacing.[7] We made sure to include information that is likely to be unknown to the farmer, based on findings from other studies that information is most valuable when individuals learn about a new technology or institutional innovation (eg. Glennerster and Suri, 2015). However, other studies also provide evidence of behavioural change occurring through the compounding or re-emphasis of common knowledge that, through repetition, becomes more salient to the individual (Duflo, Keniston, and Suri, 2014). Therefore, the videos also contain information that farmers are assumed to know but do not seem to act upon.

However, not all constraints to maize productivity improvement are information deficiencies directly related to the use of inputs, technologies, and crop management practices. Often, missing information problems manifest indirectly, as uncertainty about the distribution of the farm-household’s profit function. This includes uncertainty about the correlations between expected and actual returns, the inter-temporality of income streams, estimates of fixed and variable costs, hidden transactions costs, probabilities of adverse events, and a range of other variables that farmers may simply be unable to conceptualize or measure. Thus, a significant portion of the videos also focuses on the costs and benefits of the different technologies and practices being promoted. In addition, the videos encourage long-term thinking, advising farmers to (a) start small and grow their farm enterprise over time,

[7]Note that the videos did not include explicit information on the use of chemical pesticides which can be effective in addressing pests but may also be hazardous to humans, animals, and the environment. The decision to exclude such information was made following a determination by the study team that currently available content on pesticide use was insufficiently attentive to issues of safe handling, application, storage, and disposal of pesticides that are warranted in any study involving human research subjects.

and (b) combine technologies and practices together rather than investing all of their money and effort into one single input, practice, or technology. In short, we encourage them to experiment with combinations of technologies and practices on a small scale in the initial season before reinvesting their gains for larger-scale replication in subsequent seasons.

We also pay attention to how the information is packaged. For instance, it is found that farmers find communicators who face agricultural conditions and constraints most comparable to their own to be the more persuasive than other communicators (BenYishay and Mobarak, 2014). Several studies point out the importance of role models on aspirations and future-oriented behavior (Bernard et al., 2015). A growing strand of the literature investigates how non-cognitive farmer characteristics such as aspirations, locus of control and self-esteem can lead to behavioural change such as technology adoption (Abay, Blalock, and Berhane, 2017). Therefore, in our video, the message is conveyed by individuals who are readily recognized as "peer farmers" and who provide information that is framed as a success story.

The video starts with the farmer-actor introducing himself[8]. The farmer-actor talks about how he used to struggle with his maize production and how at one point in time, he decided things needed to change. It is shown how the farmer sells a hen, obtains a small loan from a friend, and uses these proceeds to buy small quantities of improved seed and fertilizer from a local retailer. The video then shows how the farmer prepares the field by collecting and applying manure. Next, the video details how the DAP is applied correctly, how maize seed are spaced at 75cm x 30cm intervals with 1 plant per hill, and what the correct timing of these activities should be. The video progresses to a field about 10 to 12 days after sowing when the maize has emerged from the soil, and the farmer-actor recommends to engage in gap filling to replace seeds that did not germinate, thereby preserving optimal plant density. The video proceeds to the field at 18 to 20 days after sowing, and the farmer-actor

[8]As mentioned above, this study focuses on the analysis of only one of three factors in a 3^3 factorial design. A second factor in the study is related to the person who provides the information, differentiating between a singe man, a single woman, or a couple (man and woman). Therefore, the video intervention actually consisted of three videos that are essentially the same except for the fact that the person who provides the information varies according to the three factor levels and one of these videos was shown to the household. As in a factorial design, factors are orthogonal to each other, the likelihood that a household gets to see a particular video is the same across the three videos, and so we measure the average impact of the three videos

recommends how weeding should be conducted with particular attention to the identification of striga and the importance of follow-up weeding two to three weeks later. The video then advances to four weeks after planting, where the farmer-actor demonstrates how Urea top dressing is done and recommends one more round of weeding at the tasseling stage.

The video then turns to a discussion about investing to get higher yields over time. The farmer-actor points out that while it may be difficult to raise cash, one can always start small (e.g., on one tenth of an acre) and reinvest the returns. He then explains that following recommended practices and using improved inputs led hem to produce 2.5 bags of maize on a small plot, which he sold for UGX 125,000 with a profit of almost UGX 90,000—as compared to previously harvesting merely one bag from the same area at a profit of only UGX 40,000. He then explains that he reinvested the difference (UGX 50,000) to increase the area under intensive maize cultivation year after year such that, over time, he was able to cultivate an entire acre using modern inputs. In the final part of the video, he reiterates his experience and again encourages the viewer to try a similar approach. The videos can be found here.

Two other treatments were incrementally added to the video treatment. For these two treatments, the IVR system and the SMS reminders, we collaborated with Viamo, a social enterprise that aims to connect individuals and organizations using digital technology to make better decisions. We set up an IVR system that provided the same information as what we recommend in the video (eg. the new way of spacing, same types of hybrid and OPV seed are recommended,...). Farm households that were allocated the IVR treatment could call a toll free number which explained the IVR system in their own language. The caller is then invited to select the number corresponding to the topic on which he or she wants more information (e.g. 1 for seed selection, 2 for spacing and seed rate, 3 for soil nutrient management, 4 for advice on weeding, 5 for pest management). Depending on what number was selected, the IVR then played an audio message of a conversation between two farmers where one farmer is telling the other farmer the recommended practice.

For the SMS campaign, we recorded telephone numbers for mobile phones owned by the household head. Households that were allocated to the SMS treatment were sent eight SMS messages over the course of the two months following the first screening of the video. The messages all followed a similar structure, where farmers were first reminded about the important technology or practice that was relevant at the particular time that the message was sent, followed by a reminder about the existence of the IVR service. For example, the first message, that was sent out around planting time, read “You will get much more maize if you use hybrid seed instead of recycled seed – Call the maize hotline on 0200522420 free for more advice!”. About one month into the growing season, the following message was sent: “When your maize is knee high, apply 1 water bottle cap of urea around each plant – Call the maize hotline on 0200522420 free for more advice!”.

Results

Balancing Checks

While we did not conduct a dedicated baseline survey, we did ask some questions before the first intervention to investigate balance. The choice of variables was based on what variables other researchers in similar studies have used in their orthogonality tests. In particular, we looked at balance tables in studies that investigate the adoption of yield improving methods and technologies using randomized controlled trials (RCTs), including Duflo, Kremer, and Robinson (2011), Karlan et al. (2014), Ashraf, Gine, and Karlan (2009) and Bulte et al. (2014). We collected household characteristics such as household size, age, and education level of household head. We then asked more specific questions related to maize farming, such as acreage and quantities produced in the last season. Furthermore, we asked if the household received agricultural extension service, whether it used improved seed, and whether fertilizer was applied. We also collected data on housing conditions (number of bedrooms) and distance to the nearest agro-input shop. As mobile phone ownership is relevant to the IVR and SMS interventions, we also report balance on household access to a mobile phone and ownership.

In Table 1, we provide descriptive statistics and balance tests for the comparisons between the three information delivery technologies. Averages for the control group are reported in the first column. We observe that few households that were included in our study had access to agricultural extension in the previous year (about 11 percent). We also observe that only about 17 percent of households reported to have used any fertilizer in the previous season and only about 34 percent reported to have used improved seed bought from a shop or agro-input dealer during the last cropping season.

Table 1: Balance tests for technology used to deliver information

	Mean	Video	+IVR	+SMS	N
Maize yield (kg/ac)	267.93	17.41	7.57	-9.15	3,959
	(230.20)	(18.97)	(11.30)	(11.93)	
Age of HH head (years)	40.50	-1.05	0.87 *	-0.73	3,910
	(14.33)	(0.88)	(0.52)	(0.55)	
HH head finshed primary school	0.37	-0.01	0.02	0.00	3,959
	(0.48)	(0.03)	(0.02)	(0.02)	
HH size	7.72	-0.30	0.42 ***	-0.21	3,959
	(3.17)	(0.22)	(0.13)	(0.14)	
Number of bedrooms	2.32	-0.12	0.10 **	-0.09 *	3,959
	(1.21)	(0.08)	(0.05)	(0.05)	
Access to extension last year	0.11	0.00	0.00	0.01	3,959
	(0.31)	(0.02)	(0.01)	(0.01)	
Has used fertilizer last season	0.17	0.04	0.01	-0.01	3,959
	(0.37)	(0.03)	(0.02)	(0.02)	
Has used improved seed last season	0.34	0.04	0.01	-0.01	3,959
	(0.47)	(0.03)	(0.02)	(0.02)	
Distance nearest agro input shop (km)	5.18	0.17	0.13	0.34	3,959
	(4.89)	(0.36)	(0.22)	(0.23)	
HH owns mobile phone	0.76	0.01	0.01	0.01	3,959
	(0.43)	(0.03)	(0.02)	(0.02)	
HH has access to a mobile phone	0.84	-0.01	0.02	-0.01	3,959
	(0.36)	(0.02)	(0.01)	(0.02)	
F-test		0.820	1.186	1.143	
P-value		0.621	0.291	0.323	

Note: First column reports control group means (and standard deviations below); Column 2 reports differences between placebo and video treatment (and standard error below), column 3 between video only and video+ivr, column 4 between video+ivr and video+ivr+SMS; ***, ** and * denote that the difference is signficantly different from zero at the 1, 5 and 10 percent level, respectively.

This suggests ample scope to increase intensification investments through extension. We also find that farmers produced on average only 268 kg of maize per acre in the first cropping season of 2017. This is substantially lower than the average yield of 618 kg per acre we find in data from the 2005/06 Uganda National Household Survey. The low yields reflect the devastating impact of the fall armyworm outbreak and adverse weather conditions that plagued East Africa in 2017 (Stokstad, 2017).

Balance is tested through calculating differences between treatment groups for each characteristic, as well as through a joint significance test (F-test) for each of the three ICTs. The second column in Table 1, denoted video, compares baseline characteristics between households that were shown the placebo video and household that were shown an intervention video. For example, we see that yields prior to the intervention are about 17 kg per acre higher in the group that was shown the video than in the group that was shown the placebo video. However, this difference is not significantly different from zero. In fact, for the placebo video versus intervention video comparison, none of the differences between baseline characteristics is significant at the 10 percent significance level, and also the F-statistic can not be rejected. In the third column, differences in baseline characteristics between households that received the intervention video and households that received IVR on top of the video are shown (indicated as +IVR). Here, we see that households in the latter group are significantly larger than households that only saw the video. They also have significantly more bedrooms and the household head is slightly older. However, we can again not reject the null that jointly, baseline characteristics are unrelated to the treatment group for this comparison. For the final comparison (comparing farmers that received video and IVR to those that additionally received SMS messages; reported in column four and denoted +SMS), we find that treatment household have slightly less bedrooms, but the effect is only significant at the 10 percent level and the joint test does not reject overall balance.

We find that about 84 percent of households have access to a mobile phone. This is encouraging, as the usefulness of IVR depends on access to a mobile phone. We find that there is no difference in this percentage between the various treatment groups. The incidence of phone ownership is also high, with about three quarters of households reporting they own a mobile. Again, this is important as the success of the SMS intervention depends on being able to receive the messages.

Attrition was low. Only 8.63 percent of the sample could not be tracked or persuaded to complete the endline survey. In addition, there were no indications that attrition rates were different for the different treatment groups: Attrition was 7.03 in the control group; 8.74 percent in the group that was shown a video; 8.90 percent in the group that was shown a video and received the IVR encouragement; and 7.45 percent in the group that also received an SMS in addition to the IVR encouragement and the video. In Appendix Table A.1 we compare baseline characteristics of attritors. We do not find any statistically meaningful differences in characteristics of attritors by treatment status.

Impact on knowledge

We start with an elaborate analysis of the Intent to Treat effects of the three technologies. For the first technology, video, we had virtually no household that refused to watch, and so the Intent to Treat effect is equivalent to the average treatment effect of the technology. This is not necessarily the case for the two other additional technologies. For instance, the IVR treatment consists of an encouragement to use the IVR system. We can not simply ignore the fact that a large proportion of farmers that were encouraged to use the IVR ended up not calling the system, as they are likely to be a non-random subset of the households that were assigned to the IVR treatment, leading to a biased estimate of the impact of the IVR technology. Also for the third treatment, the SMS reminders, being allocated the treatment does not necessarily mean that the household also receives the SMS message. Also here, the probability that a particular household does not receive the intended treatment is likely non-random. For instance, households that live further away from a mobile phone tower may be more likely to experience technical issues leading to delays or non-delivery of the SMS message. Even though we feel that, from a policy perspective, the Intent to Treat analysis is the most informative, we also discuss Local Average Treatment Effects below in an attempt to get a better estimate of the efficacy of the different technologies itself.

We first test the impact of the three different ICT interventions on knowledge. This was done through a short quiz (Feder, Murgai, and Quizon, 2004a,b; Masset and Haddad, 2015) consisting of four questions that were asked during the endline survey to each of the two spouses in the farm household separately. For each question, three possible answers were read out to the respondent, who was then asked to indicate which answer he or she though was correct. The respondent was also allowed to indicate if he or she did not know the correct answer. The household was considered knowledgeable on a particular topic if at least one of the spouses indicated the correct answer.

The first question was related to planting. In our video, we recommended a spacing of 75cm x 30cm with 1 plant per hill, and this was the correct option. Other possible answers included a spacing of 75cm x 60cm with two plants per hill, which is standard for many farmers and recommended by many agricultural extension agents, and an intermediate alternative of 75cm x 30cm with 2 seeds per hill. Because our video recommended a technique that deviates from what is assumed to be standard spacing, we assume that the recommended practice is new to most of the farmers. The second question is less related to technical knowledge, but more to viewing farming as a business. In the video, we paid ample attention to promoting an approach where farmers start small and grow over time by reinvesting, and we emphasized the benefits of combining inputs rather than investing only in e.g., improved seed. We want to see if farmers internalize this advice and ask what a successful farmer would do if he or she only has 40,000 shillings. The correct answer is to use this sum to purchased improved seed and fertilizer and start intensified farming on a small area. Alternative options were to: "use all the money to buy hybrid seeds, because without good seeds, yields will be low"; and "use all the money to buy fertilizer, because with poor soils, yields will be low". For the third questions, we asked if farmers knew when weeding is most important. The video showed that weeding is most important during the first four weeks after planting, as maize is a poor competitor for light and nutrients. It is assumed that most farmers would know this. Alternative answers were: "when the maize is knee high" and "when the maize is at tasseling stage," Finally, we asked if farmers knew when spraying against fall armyworm is most effective. There was no information given about fighting fall armyworm in the intervention, so unless one of our interventions encouraged farmers to search for additional information, we do not expect an impact. For this question, the correct option was: "During the evening, as fall armyworm eats during night," while the other options were: "Early in the morning when it is still cool" and "At noon because sunlight increases chemical performance."

To guard against over-rejection of the null hypothesis due to multiple inference, outcomes of the knowledge questions were combined into an index, constructed as the weighted mean of the individual standardized outcomes, using as weights the inverse of the co-variance matrix of the transformed outcomes (Anderson, 2008). However, we also think it is interesting to look at the impact on the questions individually, as they attempt to measure different aspects of the information intervention. To control the Family Wise Error Rate (FWER) when we look at scores for each question individually, we use re-randomization to construct the joint null distribution for the family of outcomes we are testing. From this family-wise sharp null, we can obtain the corresponding FWER-consistent significance thresholds by determining which cuttoffs yield e.g., 10 percent, 5 percent and 1 percent significant hypothesis tests across all tests and simulations.

Table 2 shows results for the three incremental levels of ICT-mediated information delivery using different dissemination technologies. The first column reports mean (and standard deviation reported below in parentheses) scores in the control group. For the four individual questions, this is simply the proportion of households that answered correctly on the particular question. For instance, we find that in 16 percent of the households in the control group, at least one of the spouses indicated the correct option among the response alternatives to the question on optimal maize seed spacing. This relatively low rate of correct responses is due to the fact that this is a fairly new and potentially controversial recommendation. We find that in about 91 percent of households, at least one spouse knew inputs were best combined and in more than 95 percent of households it was known that weeding is most important during the first 4 weeks. In about one third of the households, at least one spouse knew how to fight fall armyworm. For the knowledge index, the mean is harder to interpret, as it is the result of a weighted mean after standardization of the individual components of the index.

In the second column, we report the impact of having been shown the video (with standard error of the estimated coefficient reported below in parentheses). We see that having been shown the video increases the likelihood that at least one individual knows the recommended spacing by 13 percentage points and this difference is significantly different from zero at the 1 percent FWER adjusted significance level (randomization inference based p-value are in the third column; significance stars denote significance as compared to FWER adjusted thresholds). We also find that the video increased the likelihood that at least one spouse indicates that inputs are best combined for optimal results by 4.5 percentage points. This difference is statistically significant at the 5 percent FWER adjusted significance level. For the question on weeding, the intervention does not seem to have a signif-

Table 2: Impact of dissemination technologies on knowledge

	Mean	Video	p-value	+IVR	p-value	+SMS	p-value	N
Knows optimal spacing (yes=1)	0.160	0.130***	0.000	-0.019	0.214	0.010	0.608	3,619
	(0.367)	(0.030)		(0.018)		(0.019)		
Knows inputs best combined (yes=1)	0.908	0.045**	0.009	-0.018	0.065	0.010	0.423	3,619
	(0.290)	(0.018)		(0.011)		(0.011)		
Knows optimal time for weeding (yes=1)	0.954	-0.017	0.297	0.009	0.306	0.000	0.984	3,619
	(0.210)	(0.017)		(0.010)		(0.010)		
Knows how to fight armyworm (yes=1)	0.336	-0.019	0.557	-0.015	0.444	0.017	0.413	3,619
	(0.473)	(0.032)		(0.019)		(0.020)		
Knowledge index	-0.077	0.127***	0.004	-0.021	0.309	0.019	0.502	3,619
	(0.562)	(0.043)		(0.025)		(0.026)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between placebo and video treatment (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 5; column 6 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 7; sample size is reported in column 8. Reported p-values are based on randomization inference (10,000 permutations); ***, ** and * denote that the difference is signficant at the 1, 5 and 10 percent level, respectively, after correcting for multiple hypothesis testing using a family-wise sharp null (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

icant effect. However, this result should be interpreted with care due limited variation in the outcome.[9] Finally, on the Fall Armyworm question, we find that households that were shown the video are no more likely than control households to know when one should spray to control the pest. This suggests that the videos did not encourage farmers to actively search information on important challenges that were not explicitly covered in the video. Overall, and as confirmed by the knowledge index, we conclude that the agricultural extension videos increased knowledge at the household level, and that this increase seems especially poignant for *new* information provided in the videos.

The fourth column (+IVR) shows the additional (ITT) effect of IVR (with standard error of the estimated coefficient reported below in parentheses; corresponding randomization inference based p-value are in the fifth column), over and above the video effect reported in the second column. We see that being provided with an IVR encouragement does not affect knowledge about the new recommended spacing. There is some indication that the IVR treatment reduces the likelihood that at least one spouse responded correctly on the question about how inputs should be combined, but the reduction is not significantly different from zero after taking multiple inference into account. Similarly, there is no effect on knowledge related to the optimal time for weeding and also no effect on knowledge about the best way to fight fall armyworm. The fact that there is no supplementary effect of the IVR encouragement on knowledge is confirmed by the non-significant difference in the knowledge index.

The sixth column (+SMS) reports the additional effect of the sms reminders on the various questions and the index (randomization inference based p-value are in the seventh column). Similar to the impact of IVR, we do not find an additional effect of the SMS campaign on any of the questions. We also do not find an effect of the SMS campaign as judged by the knowledge index.

It may be that the null results for both IVR and SMS campaign are due to the fact that we average over both households that have access to a mobile phone and those who do not. As the IVR and SMS treatments are likely to be most effective if households have access to or own a mobile phone, averaging over all household may dilute the effect, making it more difficult to detect a significant difference with the control group. Therefore,

[9] In fact, our pre-analysis plan specifies that we would drop from the analysis variables where 95 percent of outcomes are the same value.

we take a closer look at conditional treatment effects. In particular, for the IVR campaign, we re-estimate the impact on knowledge again, but only for the 3,002 households that reported to have access to a mobile phone (either because someone within the household owns a mobile phone or because they can use the phone of a neighbor or relative if necessary). For the SMS campaign, access to a mobile phone is likely not sufficient. To get the most benefit from the SMS reminders, households need to own a mobile phone. We therefor reran the analysis for the subset of 2,736 farm households that reported to own a mobile phone. However, results, reported in Table A.2, are very similar to the results obtained from the analysis on the entire data set, with no additional effects from neither IVR nor SMS reminders on knowledge.

Furthermore, especially for the IVR encouragement, the analysis above estimates the effectiveness of the intervention in increasing knowledge, adoption and production outcomes. It does not provide an estimate of the efficacy of the IVR treatment itself. To get to the effect of the IVR system itself, we need to consider compliance: did farmers also use the IVR system. For the IVR treatment, compliance was measured by comparing the phone numbers extracted from the IVR call log with the phone numbers that were given to us by the farmers at baseline. We find that only a small number of households that were encouraged to use the IVR system also actually called in (8.9 percent or 214 households)[10]. In addition, we also found that 22 households that did not receive the encouragement called the IVR system. Compliance may also not be perfect for the SMS treatment. For the SMS reminders, the system reported which households received the message. Of the 1,113 house-

[10]This is a very low compliance rate, which partly reflects low demand for the service. Cole and Fernando (2016) find that for a similar service in India, compliance rates were as high as 88 percent. Among possible explanations for this difference are: the time frame (the 88 percent was measured after 2 years of intensive exposure to the system, compliance rates were much lower at midline, while our IVR system was only 3 months operational); differences in treatment intensity (we only sent 8 reminders while Cole and Fernando (2016) sent bi-weekly reminders); the different study population of Cole and Fernando (2016), that consisted of cotton farmers that expressed willingness to participate and owned a mobile phone; different technologies (hotline where direct questions can be asked to real person extension agents vs IVR that works with pre-recorded messages and a limited set of options). However, there are also signs that our indicator of compliance may under-report true compliance (because for instance encouraged farmers use different phones to call the hotline). This is illustrated by the fact that about 430 unique calls were made to the hotline, representing about 18 percent of encouraged households. Unfortunately, we did not enquirer if farmers called the hotline during endline data collection.

holds that were supposed to receive the reminders, only 860 or 77.3 percent did. We therefore also estimate Local Average Treatment Effects (LATE), where the IVR encouragement is used as an instrument for having called into the IVR system. Similarly, we report two stage least squares results where allocation to the SMS treatment is used as an instrument for having received the SMS message. Note that for the former, due to the potential of two-way non-compliance, we need both excludability and monotinicity, while for the latter, there is only one-way non-compliance, hence only the exclusion restriction is needed.

Appendix Table A.3 repeats average scores for the control group in the first column for reference. In the second and third columns, we report results of a two stage least squares (2SLS) regression where the endogenous variable, an indicator that takes the value of one if the household called the IVR, is instrumented by the IVR treatment allocation. We conclude that, as judged by the LATE estimates, calling the IVR system did not affect knowledge. In the fourth and fifth columns, we report LATE estimates for the SMS reminders. Results of a 2SLS regression where the endogenous variable, an indicator that takes the value of one if the household received at least one SMS message, is instrumented by the SMS treatment allocation. As for the ITT effect, we also find no TOT effect as evaluated through LATE.

There may be different reasons why we do not find additional knowledge effects of the IVR encouragement and the SMS reminders. First, the lack of additional effects may be due to the way the experiment was designed. As we wanted to rule out that the effects were driven by differences in the content, we made sure that no new information was given in the IVR system and in the SMS campaign. In fact, we were interested in testing if IVR is effective in mitigating the fact that video is a one-off intervention and farmers may forget the details related to new and complex agronomic practices. Also for the SMS campaign, the messages are too concise to transfer new knowledge. The aim here was to simply remind farmers about what they learned in the video and encourage them to call the hotline. In light of this, it may be less surprising that we do not find additional knowledge effects from the two interventions. The null result for the IVR treatment on knowledge is also consistent with Cole and Fernando (2016), who also do not observe differences between the treatment and control groups in agricultural knowledge in their midline or in their endline survey from a hotline. They argue that this was, to some extent, to be expected: as a demand-driven service, the types of knowledge that respondents gain reflect their actual demand for information. Also in our case, we did not test knowledge on the topics that were chosen most frequently by the farmers that used the IVR system (pests and diseases and land preparation and seed selection)[11].

Adoption effects

During the endline survey, we collected detailed information on the adoption of recommended farming practices on maize plots. Results of mean adoption rates in the control group for different practices are reported in the first column of Table 3. For instance, in the video, we recommend to start planting maize immediately after the start of the rains. We find that 37 percent of households in the control group reported that they started planting one day after the start of the rains on at least on plot. Below, we show that only 2.6 percent of households in the control group used the recommended way of plant spacing of 75cm x 30cm with a reduced seed rate of 1 seed per hill. This low rate in the control group is not surprising given that this was a new and somewhat controversial recommendation. Almost 69 percent of control households report removing striga before it flowers to reduce damage early on and prevent the weed from spreading. Finally, we find that about 43 percent of control households reported first weeding after 18-20 days as recommended in the video.

The second column in Table 3 again reports the difference in the adoption of practices between households that were shown the video and households that were give the placebo treatment (with standard error of the estimate in parenthesis below; corresponding randomization inference based p-values are in column 3). We find that for the first recommended practice, early planting, there is no impact from the agricultural extension information video. The likelihood that households adopt the recommended 75cm x 30cm spacing with a reduced seed rate increases significantly after having been shown the video: While only 2.6 percent of households report adopting this practice on at least one plot, this percentage increases to 8.9 percent in the group of households that was shown a video (and this difference is significant at the 1 percent FWER corrected significance level). Similarly, we find that the proportion of households that removed striga early on increased from 68.5 percent to 74.7 percent as a result of being shown a video (randomization inference p-value

[11] We did test knowledge related to the fall armyworm pest. However, the IVR system did not include information on this.

Table 3: Impact of agricultural extension videos on adoption of recommended practices

	Mean	Video	p-value	+IVR	p-value	+SMS	p-value	N
Planted immediately after start of rains (yes=1)	0.370	-0.004	0.899	0.009	0.635	-0.002	0.944	3,500
	(0.484)	(0.034)		(0.020)		(0.021)		
Used spacing of 75cm x 30cm with a reduced seed rate (yes=1)	0.026	0.063***	0.001	-0.005	0.620	0.014	0.289	3,560
	(0.158)	(0.019)		(0.011)		(0.012)		
Removed striga early on (yes=1)	0.685	0.062*	0.020	-0.009	0.693	0.024	0.231	3,560
	(0.465)	(0.031)		(0.018)		(0.019)		
First weeding after 18-20 days (yes=1)	0.426	0.019	0.585	0.013	0.487	-0.009	0.724	3,560
	(0.495)	(0.034)		(0.021)		(0.022)		
Recommended practices index	-0.086	0.100***	0.003	0.005	0.760	0.020	0.395	3,500
	(0.478)	(0.037)		(0.022)		(0.023)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between placebo and video treatment (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 5; column 6 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 7; sample size is reported in column 8. Reported p-values are based on randomization inference (10,000 permutations); ***, ** and * denote that the difference is signficant at the 1, 5 and 10 percent level, respectively, after correcting for multiple hypothesis testing using a family-wise sharp null (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

of 0.020, significant at the 10 percent FWER corrected significance level). Finally, while the proportion of households that reports they started weeding after 18-20 days is almost 2 percentage points higher among households that were shown the video, the difference is not significantly different from zero. The index that summarizes the different practices confirms that overall, we conclude that agricultural extension videos significantly increased the adoption of recommended practices. Results suggest this is particularly the case if it concerns practices that are new and less likely to be known by the farmers.

The fourth and fifth column of Table 3 report results for the additional effect of the IVR encouragement (Intent to treat estimate in column 4, corresponding randomization p-values in column 5). We do not find any significant additional effect of the IVR treatment on any of the recommended practices. The sixth and seventh column report results for the additional effect of the SMS campaign (Intent to treat estimate in column 6, corresponding randomization p-values in column 7). While we do find that the proportion of households that reports to be removing striga before it flowers is 2.4 percentage points higher in the treatment group and we also find a small positive effect on seed spacing and seed rate, the differences are not significant. The fact that the both the IVR encouragement and the SMS campaign has no impact on adoption of practices is also reflected in the index.

Similar to the analysis for knowledge outcomes, we repeated the analysis to assess the sensitivity of the results to potential treatment heterogeneity related to mobile phone access. In particular, we redid the analysis for the additional effect of IVR encouragement, but only for the households that reported to have access to a mobile phone. Results for this are reported in columns 2-4 in Appendix Table A.4. In addition, we repeat the analysis for the additional impact of the SMS campaign, but restricting our sample to only the households that reported owning a mobile phone. Results for this are in columns 5-7 of Appendix Table A.4. Results are very similar to those reported in Table 3 and so we conclude that our lack of results is not driven by treatment heterogeneity with respect to mobile phone ownership or access. In Appendix Table A.5, we account for non-compliance in the IVR and SMS treatments when looking at adoption. As in Table A.3, we use 2SLS and instrument callers with the IVR encouragement and recipients of at least one SMS message with treatment allocation to the SMS reminder campaign. For the efficacy of both treatments on agronomic practices, there is no impact.

We also asked detailed questions on the adoption of modern inputs. In particular, we examine the effect of video-enabled extension on fertilizer and seed use on maize plots. Results are reported in Table 4. In the top panel of the table, we look at the three types of fertilizer that were recommended in the video separately, and again use an index to assess changes in overall fertilizer use. Again, the first column in Table 4 reports mean adoption rates in the control group. We find that 26.4 percent of households report that they used DAP or NPK on at least one of their maize plots. The use of urea is less widespread: only 5.1 percent of households in the control group report that they used Urea on at least one plot. Among control households, 15.7 percent reports using organic fertilizer on at least one plot.

The impact of showing agricultural extension videos on fertilizer use is reported in column 2 and 3 of Table 4. We see that showing a video reduced the use of DAP or NPK by 4.7 percentage points. This difference has an associated randomization inference based p-value of 0.088. However, it is not significant after controlling FWER. We find the reverse for Urea use: here, we record a increase of almost 5 percentage points (randomization inference based p-value of 0.011, and significant at the 5 percent level after controlling FWER). We also find that the use of organic fertilizer increased by about 50 percent as a result of the video treatment. Summarizing the three types of fertilizer in a index results in a positive difference between treatment and control, and the difference is significant at the 10 percent level.

The opposing effects of the video on different types of fertilizer, the inorganic types in particular, may be due to the fact that in the video, we pay particular attention the benefits of combining inputs and technologies. The video may thus encourage farmers to reassess their mix of fertilizers, reducing the use of fertilizer types that are already used widely and increasing the use of fertilizer types that are less commonly used. In the light of this reasoning, the fertilizer index may need to be specified differently, as more is not necessarily better for each type of fertilizer. More in particular, in the light of the imbalance in the control group, one may argue that DAP/NPK use is higher than optimal and Urea use is lower than optimal. As such, a case can be made to include DAP/NPK use in the index with a negative sign. Doing so, we conclude that the video intervention has a significant effect on the fertilizer mix used by farmers (with a randomization inference p-value $<$ 0.001).

The supplementary impact of the IVR encouragement is reported in columns 4 and 5 of Table 4. While the difference between treatment and

Table 4: Impact of dissemination technologies on fertilizer and improved seed use

	Mean	Video	p-value	+IVR	p-value	+SMS	p-value	N
				fertilizer use				
Used DAP/NPK on at least one plot? (yes=1)	0.264	-0.047	0.088	0.021	0.146	-0.008	0.725	3,560
	(0.442)	(0.029)		(0.017)		(0.018)		
Used urea on at least one plot? (yes=1)	0.051	0.049**	0.011	0.012	0.271	-0.021	0.113	3,560
	(0.221)	(0.020)		(0.012)		(0.013)		
Used organic fertilizer on at least one plot? (yes=1)	0.157	0.077***	0.005	-0.038**	0.012	0.032	0.102	3,560
	(0.365)	(0.028)		(0.017)		(0.018)		
Fertilizer index	-0.057	0.083*	0.035	-0.004	0.815	-0.002	0.984	3,560
	(0.547)	(0.042)		(0.024)		(0.026)		
				improved seed use				
Used hybrid maize seed on at least one plot? (yes=1)	0.289	0.006	0.865	0.040	0.022	-0.046	0.029	3560
	(0.454)	(0.031)		(0.019)		(0.020)		
Used Open Polinated Varieties on at least one plot? (yes=1)	0.302	-0.029	0.379	0.009	0.590	0.024	0.440	3560
	(0.460)	(0.031)		(0.019)		(0.020)		
Seed index	0.032	-0.026	0.559	0.053	0.030	-0.023	0.536	3558
	(0.700)	(0.048)		(0.028)		(0.029)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between placebo and video treatment (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 5; column 6 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 7; sample size is reported in column 8. Reported p-values are based on randomization inference (10,000 permutations); ***, ** and * denote that the difference is signficant at the 1, 5 and 10 percent level, respectively, after correcting for multiple hypothesis testing using a family-wise sharp null (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

control is positive for both types of inorganic fertilizer, the effects are not significant. We do, however, find that the IVR encouragement reduced the proportion of households that reports using organic fertilizer by about 25 percent. This negative impact may again be explained by a change in the mix of fertilizer. In the context of a more demand driven technology, farmers that use organic fertilizer may seek information on more efficient types of fertilizers. If we judge the effectiveness of the IVR encouragement by including organic fertilizer use in the index with a negative sign, we do indeed find a significant impact (randomization inference p-value = 0.009). The additive effect of the SMS campaign is reported in columns 6 and 7 of Table 4. We find that the SMS reminders reduced the likelihood of using Urea and increased the likelihood of using organic fertilizer, but none of the differences is significant.

In the lower panel of Table 4, we report results for the use of modern seed. We differentiate between hybrid seed varieties and open pollinated varieties. In the first column, we see that use of improved seed is more common than fertilizer use: in the control group, about 30 percent of households report using open pollinated varieties on at least on plot, and this percentage is only slightly lower for hybrid varieties. We do not find that having been shown a video changes these percentages (columns 2 and 3). We do find an effect from the IVR encouragement: the percentage of households that reported to have used hybrid seed on a least one plot was 4 percentage points higher in the treatment group. Apparently, providing farmers with a tool that allows them to actively seek out information about a new and complicated technology increases the likelihood that they also adopt it. The impact of the IVR treatment on improved seed use is confirmed by the seed index. The addition of SMS reminder, on the other hand, does seem to reduce the likelihood that hybrid maize seed is used (columns 6 and 7). However, the effect ceases to be significantly different from zero after controlling FWER. The effect of the SMS campaign on the seed index is also insignificant.

We again investigate robustness of the results for the IVR and SMS interventions by rerunning the analysis conditional on mobile phone ownership. The results from this analysis is presented in Appendix Table A.6. We find that for the subset of households that have access to a mobile phone, the IVR encouragement still reduces the likelihood of using organic fertilizer and increases the use for DAP/NPK (but not for Urea). If we include organic fertilizer use with a negative sign in the index, we still conclude that the IVR treatment significantly affects fertilizer allocation (randomization inference p-value=0.006). The addition of SMS reminders reduces Urea use more in the subgroup of phone owners (randomization inference p-value=0.050), but the estimate is not significantly different from zero after controlling FWER. We also find that organic fertlizer use is slightly higher among households that were allocated to the SMS treatment. Judged by the fertilizer index, there is also no additional effect of SMS on fertilizer use. The effect of the IVR treatment on seed use becomes insignificant if we restrict ourselves to the subset of farmers that have access to a mobile phone, while the negative effect of the SMS campaign on hybrid seed use now becomes significant at the 10 percent FWER controlled significance level.

Results for the TOT effects on inputs are somewhat more interesting than TOT effects on agronomic practices (see Appendix Table A.7). Interestingly, we find a substantial reduction in the use of organic fertilizer if farmers make use of the IVR system. We also find a significant effect of having received at least one SMS message. The effect of the SMS reminder reverses the IVR effect somewhat, but the effect size is very low. We further find that farmers that called the IVR line are much more likely to use hybrid seed. Also here, the effect is reversed by the SMS treatment.

Production effects

We now turn to the intervention's effects on production-related outcomes. We first look at household-level maize production. During the endline survey, we asked both spouses separately to estimate how much maize was harvested from each plot. These quantities were then summed over the different maize plots for each spouse and the average between the two spouses was taken as the final estimate of household-level maize production. We find that overall, a typical household in our sample produced about 500 kg of maize on an average of 1.16 acres. We further find that yields, defined as kilograms per acre, amounted to on average 530 kg per acre.

The first column in Table 5 shows mean values for the production indicators. It shows that on average in the control group, households produce (log(kg)) 5.814 or about 440 kg of maize. This was cultivated on (log(acre)) 0.018 or about 1.19 acres on average. It also shows that for the average household in the control, maize yields (log(kg/acre)) equal 5.850 or about 430 kg/acre.This is much higher than yields recorded at baseline (290 kg/acre) for the previous season, possibly because the rains were better during our intervention and farmers may have given greater attention to combating Fall

Armyworm. Still, compared to figures recorded in FAOSTAT (1000 kg/acre) or figures from household survey data (typically around 600 kg/acre), yields were below what might be considered "normal" in Uganda. This is also confirmed by the fact that in less than 40 percent of households at least one spouse reported that yields were better than a typical year on at least one plot. We also look at labour use. The average household spent about 72 mandays on maize farming, which includes labour that was hired in. This translates in a labour productivity of 6.73 kg of maize per hour worked.

In the second column of Table 5 we report the impact of the agricultural extension video campaign (with corresponding randomization inference based p-values in column 3) for the various production related outcomes. We see that there is no impact on (log) maize production. However, we do see that households that were shown the video produce this same amount of maize on an area that is about 9.6 percent smaller than the area used for maize production by households in the control group. As a result, we also find that among households that were shown a video, yields are about 10.3 percent higher than among the control group that saw a placebo video, and this difference is significant at 10 percent after controlling FWER. We do not find that households that were shown a video are more inclined to feel that yields are better than normal than households in the control group. With respect to labour, we do not find any effects in the extensive nor the intensive margin.

Results are again consistent with the message that is provided in the video. In particular, it is advised that farmers experiment on a small part of the field with modern inputs, following recommended practices. It is also advised against planting the entire field with eg. improved seed if this leaves no more money for complementary inputs such as fertilizer. Rather, it is suggested that the farmer should combine inputs on a small area than to put all eggs in one basket. Finally, the video also promotes a more commercial mindset, and pays ample attention the the idea of starting small and growing over time through re-investing. The fact that the video intervention has a clear effect on production related outcomes is also reflected in the significant different in the production index between treatment and control.

Columns 4 and 5 report the additive effect of the invitation to use the IVR system on production related outcomes. As with previous outcomes, there seems to be little impact from this treatment. The only exception is maybe labour productivity, which is about 6.4 percent higher among households that received the IVR start kit. However, while this difference has an associated

Table 5: Impact of dissemination technologies on production outcomes

	Mean	Video	p-value	+IVR	p-value	+SMS	p-value	N
Maize production (log(kg))	5.814	-0.013	0.804	0.048	0.202	0.040	0.340	3,344
	(0.765)	(0.059)		(0.035)		(0.036)		
Maize area (log(acre))	0.018	-0.092*	0.034	-0.014	0.573	0.023	0.462	3,341
	(0.580)	(0.045)		(0.026)		(0.028)		
Maize yield (log(kg/acre))	5.850	0.098*	0.028	0.036	0.266	0.004	0.913	3,302
	(0.658)	(0.049)		(0.029)		(0.030)		
Yield better than normal (yes=1)	0.387	0.023	0.496	0.000	0.991	0.035	0.149	3,560
	(0.488)	(0.034)		(0.020)		(0.021)		
Labour(log(mandays))	4.132	-0.010	0.790	-0.003	0.915	0.027	0.348	3,370
	(0.577)	(0.042)		(0.024)		(0.026)		
Labour productivity (log(kg/mandays))	1.650	0.028	0.592	0.062	0.070	0.000	0.955	3,341
	(0.720)	(0.057)		(0.033)		(0.035)		
Production index	-0.053	0.058*	0.024	0.008	0.581	0.005	0.712	3,302
	(0.365)	(0.026)		(0.015)		(0.016)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between placebo and video treatment (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 5; column 6 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 7; sample size is reported in column 8. Reported p-values are based on randomization inference (10,000 permutations); ***, ** and * denote that the difference is signficant at the 1, 5 and 10 percent level, respectively, after correcting for multiple hypothesis testing using a family-wise sharp null (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

p-value of 0.070, it is not significant after considering multiple comparisons. Similarly, we do not find additional effects on production related outcomes of the SMS campaign. Also for production related outcomes, we investigate if results are different if we restrict to households that have access to a mobile phone (for the IVR treatment) and if we restrict to households that own a mobile phone (for the SMS treatment). Results can be found in Appendix table A.8. Also in the appendix, we report TOT estimates (Table A.9). In both cases, we do not find additional effects of IVR nor SMS on production related outcomes, except maybe on labour productivity.

The impact on disposal

We next investigate if the interventions also have an impact on how households dispose of the maize they produce. We look at 3 different ways of disposal: maize consumption by the household itself, maize sold on the market, and maize saved as seed for the next season. Results are presented in Table 6. The first column in the table shows that, not surprisingly, a large share of the households report positive amounts of maize consumed (83.5 percent). We also find that a large share of household report that they sell part of their maize (about 64.3 percent of households). This is about twice the market participation rates commonly found in the literature, underlining the importance of maize for our study population as a source of income (Barrett, 2008). We also find that 85 percent of households save maize to be used as seed in the next season, illustrating the prevalence of seed recycling and reliance on informal seed systems among smallholders (McGuire and Sperling, 2016).

The second column in Table 6 reports the impact of the agricultural extension video (with corresponding randomization inference based p-values in the third column). We find that the proportion of households that reports consuming maize is almost 3 percentage points higher among households that was shown a video, but the difference is not significantly different from zero. We also find 1.8 percentage points more households report selling maize in the sub-sample that was shown the video, but also here, the effect is not significant. Furthermore, we find that the share of households that reported they saved maize to be used as seed in the next season is 3.3 percentage points lower among households that received the video treatment. This is probably because the video underscores the importance of using high quality seed, and advises against recycling seed. Also here, the difference is not statistically significant. However, if we combine the three types of disposal in an index, with maize saved as seed entered negatively, we do find that disposal is affected by the video treatment (albeit only at a 10 percent significance level). The fact that the index is significant but the individual outcomes are not is due to the increased efficiency by ensuring that outcomes that are highly correlated with each other receive less weight, while outcomes that are uncorrelated and thus represent new information receive more weight (Anderson, 2008).

In the fourth and fifth column, we report the additional effect of the IVR encouragement. There are no additional effects of the IVR on home consumption, nor on the likelihood that households sell part of the maize. We do find among households that also received the IVR treatment, the proportion of households that saved maize as seed for the next season reduced by an additional 2.4 percentage points. However, with a randomization inference based p-value of 0.113, this difference is not significant. The index also confirms that we can not reject the null of no additional effect from the IVR treatment. In the sixth and seventh column, results are presented for the additional impact of the SMS reminders. We do not find any additional effect of this treatment on maize disposal outcomes. In Appendix Table A.10, we again estimate conditional treatment effects, but results for the IVR and SMS treatments are again not sensitive to phone access and ownership. Appendix Table A.11 reports TOT estimates for the effect of calling the IVR help line and receiving SMS reminders on disposal. Also here, we do not find an effect on maize consumption, the probability that maize is sold or the likelihood that maize is saved for seed.

The impact on household welfare

Finally, we look at the impact of the information interventions on measures of well-being at the household level. Welfare is captured though self-assessment, as well as though consumption expenditure. We asked welfare related questions to the woman within the household, as we assume she has a better idea of consumption expenditure within the household and the general level of well-being. First, we asked if they feel their household is better off (as opposed to equally well off or worse off) in terms of income and consumption than the average households in their community. We find that among the control group that was shown the placebo video, about 39.7 percent of households felt they were better off than average (first column in Table 7). We find

Table 6: Impact of dissemination technologies on maize disposal

	Mean	Video	p-value	+IVR	p-value	+SMS	p-value	N
Consumed maize (yes=1)	0.835	0.029	0.209	-0.003	0.837	0.009	0.651	3,617
	(0.372)	(0.024)		(0.014)		(0.015)		
Sold maize (yes=1)	0.643	0.018	0.586	0.002	0.924	-0.010	0.654	3,569
	(0.480)	(0.033)		(0.020)		(0.021)		
Saved maize for seed (yes=1)	0.854	-0.033	0.211	-0.024	0.113	0.017	0.369	3,533
	(0.354)	(0.028)		(0.017)		(0.017)		
Disposal index	-0.059	0.065*	0.100	0.025	0.241	-0.017	0.524	3,531
	(0.510)	(0.040)		(0.023)		(0.024)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between placebo and video treatment (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 5; column 6 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 7; sample size is reported in column 8. Reported p-values are based on randomization inference (10,000 permutations); ***, ** and * denote that the difference is signficant at the 1, 5 and 10 percent level, respectively, after correcting for multiple hypothesis testing using a family-wise sharp null (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

that among the control households, 38.8 percent indicated they were better off than six months ago. We also include two standard self assessed food security questions taken from the Household Food Insecurity Access Scale (HFIAS) (Coates, Swindale, and Bilinsky, 2007). We asked if households were generally able to eat their preferred food. Approximately 41.8 percent of households responded affirmatively. We also asked if households were generally able to eat enough food and found this to be the case in almost 60 percent of baseline households.

As a less subjective way to asses changes in well-being, we collected data on consumption. In particular, we asked the woman in the household about the value of the most consumed items, including own-consumption from farm production over the period of one week. These included consumption of maize, cassava, sorghum, millet, rice, sweet potatoes, beans, fruits, groundnuts, vegetables, salt/sugar, cooking oil/ghee, soap, and airtime[12]. From this we then took the logarithm and trimmed at 5 percent. We find that log consumption expenditure is about 10.92 in the control group, which corresponds to about UGX 65,000 or just under USD 20 per household per week.

As in the tables on the impact of other outcome categories, the second and third table in Table 7 reports average treatment effects for the video intervention. We find no evidence of impact on any of the welfare indicators. In the next two columns, we report intent to treat effects for the IVR intervention. Also here, we only find null effects. Finally, in columns 6 and 7 we report intent to treat effects for the addition of the SMS campaign. There is also no effect of the SMS reminders on outcomes. We also report conditional effects for subsets of farmers depending on mobile phone access/ownership (Appendix Table A.12). TOT effects for the IVR and SMS interventions are reported in Appendix Table A.13. Also here, we do not find any additional welfare effect.

[12]Even though these consumption categories were carefully chosen on the basis of consumption expenditure data from representative surveys in the area, we agree they may not capture everything and the estimates are likely to be too low. In addition, it may be that the intervention affected the composition of consumption, and farmers that had seen the video may have started consuming more of a food category that we did not measure, suggesting their consumption did not change. Care should thus be taken when interpreting this variable.

Table 7: Impact of dissemination technologies on household welfare

	Mean	Video	p-value	+IVR	p-value	+SMS	p-value	N
Is your household better off than average? (yes=1)	0.397	0.038	0.258	-0.024	0.237	0.018	0.430	3,617
	(0.490)	(0.034)		(0.020)		(0.021)		
Is your household better off than 6 months ago? (yes=1)	0.388	0.039	0.259	-0.026	0.130	0.039	0.108	3,617
	(0.488)	(0.034)		(0.020)		(0.021)		
Is able to eat preferred food? (yes=1)	0.418	-0.016	0.649	0.008	0.656	0.015	0.502	3,617
	(0.494)	(0.034)		(0.020)		(0.021)		
Is able to eat enough food? (yes=1)	0.591	-0.031	0.382	0.002	0.905	0.027	0.247	3,617
	(0.493)	(0.034)		(0.021)		(0.022)		
Consumption expenditure (log)	10.924	-0.016	0.563	0.009	0.882	-0.035	0.789	3,423
	(0.568)	(0.040)		(0.023)		(0.025)		
Welfare index	0.032	0.001	0.986	-0.014	0.595	0.010	0.652	3,423
	(0.582)	(0.043)		(0.025)		(0.027)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between placebo and video treatment (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 5; column 6 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 7; sample size is reported in column 8. Reported p-values are based on randomization inference (10,000 permutations); ***, ** and * denote that the difference is signficant at the 1, 5 and 10 percent level, respectively, after correcting for multiple hypothesis testing using a family-wise sharp null (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

Table 8: Impact of SMS reminders on calls made to IVR

	Mean	ITT	p-value	LATE	p-value	N
Called IVR	0.065	0.061	0.000***	0.081	0.000***	2,193
	0.247	0.013		0.017		

Note: In the first column, means (and standard deviations) in the comparison group. *** denotes significant at 1 percent level. All specifications control for the other orthogonal factors in the factorial design.

Impact of SMS campaign on IVR

The SMS campaign does not appear to have any effect on the outcomes above. This is surprising, as timely reminders have often been found very effective in overcoming inertia, procrastination, competing obligations, or simple forgetfulness of human beings (Sunstein, 2014). At the same time, an SMS message of 160 characters may not provide sufficient space to transfer knowledge on complex agronomic practices or promote new technologies that really matter for productivity. However, an important aim of the SMS campaign was also to remind farmers that they can call the IVR system to get agricultural extension information. Each message ended with the instruction to “Call the maize hotline on 0200522420 for free to get more advise!”.

Table 8 shows that the SMS messages did seem to serve the purpose of additionally encouraging people to use the IVR. We restrict attention to households that received the IVR encouragement. We see that among households that received the IVR encouragement but were not allocated to the SMS treatment, only 6.5 percent actually called the IVR line (column 1). This percentage was 6.1 percentage points higher among households that received the IVR encouragement and were also allocated to the SMS treatment (column 2 and 3). If we use SMS allocation to the treatment as an instrument for actually receiving the SMS messages (coumns 4 and 5), the effect increases to 8.1 percentage points.

Conclusion

In this study, we evaluated the effectiveness of three complementary ICT-enabled agricultural extension approaches that can be brought to scale relatively easily and at significantly lower cost than traditional modes of agricultural extension. The first approach, the use of short, appealing video messages, is probably closest to the traditional extension approach which involves in-person visits to farmers and demonstration. While appealing because of its ability to combine both audio and visual information, the approach is also somewhat top-down, with only a passive role of the farmer in the knowledge exchange process. [13] The second approach, Interactive Voice Response (IVR) assumes a more active role for the farmer. Here, the farmer calls into a system that lets him or her choose a topic from a menu, after which the farmer gets the hear a pre-recorded message. Finally, the third approach consists of a series of SMS messages that reminds the farmer of particular key inputs or practices. Reminders such as this have been found key nudges in a variety of other contexts (eg. Johnson et al., 2016).

We tested the relative effectiveness and efficacy of these three ICT-enabled agricultural advisory approaches using a field experiment among nearly 4,000 smallholder maize farmers in eastern Uganda. To assess the effectiveness of video as an extension approach, we compared outcomes of a random subset of farmers that was shown an informational video to a random subset of farmers that was shown a placebo video. Furthermore, two third of the farmers that was shown a video were randomly sampled and encouraged to use the IVR, and among those that were allocated to the IVR encouragement, half was randomly selected to also receive 8 reminder SMS messages. As such, we could estimate the additional effect of the IVR and SMS treatments. Effectiveness was measured in terms of knowledge gained, practices and technologies adopted, production increased, disposal affected and welfare improved. We also considered conditional treatment effects and non-compliance.

In our study, we found that video-enabled agricultural extension information campaigns affected a range of outcomes. Showing agricultural extension information videos to maize farmers increased knowledge, particularly about new practices and technologies. The videos also increased the adoption of these new recommended agronomic practices. Videos also led to adjustment of fertilizer use, with farmers increasing the use of certain types of fertilizers (urea and organic) and reducing the use of others (DAP, NPK). This led to more balanced soil fertility management. As a result, farmers that were shown agricultural extension videos also increased maize yields by 10 percent. This was mainly because these farmers farm more intensively (producing the

[13] The top-down nature of videos can be lessened by a using participatory process of content creation (Gandhi et al., 2009).

same amount but on smaller plots). There is some evidence that farmers that were shown the video saved less seed for planting (and thus planned to buy (improved) seed from the market for the next season. We did not find an impact on well-being.

Interactive Voice Response (IVR) did not seem to affect knowledge. We also found no impact on agronomic practices. We did find some evidence that farmers that were encouraged to use the IVR were more likely to use hybrid seed. We found no effect of IVR on production, disposal, nor well-being. Short Message Service (SMS) messages, sent at strategic times to remind farmers about important practices and to further encourage them to use the IVR system did not have any additional effect. The results (or lack thereof) for the IVR and SMS treatments are robust to incorporating non-compliance and persist if effects are estimated conditional on mobile phone ownership.

One area that needs further attention is related to spillovers. It is well known that experimental studies of information treatments are especially prone to non- interference violations (Coppock, 2014). As such, our estimates are likely to underestimate the true effects of ICT-mediated extension approaches. At the other hand, there is considerable evidence that much of the learning among smallholders happens through peer learning (Bandiera and Rasul, 2006; Conley and Udry, 2010). Some studies try to understand how peer learning can be leveraged to accelerate agricultural technology adoption and diffusion (eg. Beaman et al., 2018). The question then becomes which ICT-mediated extension approach maximizes spillover effects, for instance through ease of sharing of content. Future studies should be designed with such questions in mind, by for example ensuring exogenous variation in treatment saturation or by using a “multilevel” design where different levels correspond to different spillover networks and treatments are assigned so as to create variation in different levels (Baird et al., 2017).

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Appendix

Table A.1: Baseline characteristics of attritors by treatment status

	Mean	Video	+IVR	+SMS	N
Maize yield (kg/ac)	232.87	66.58	26.37	-67.69	342
	(230.63)	(54.10)	(29.58)	(32.56)	
Age of HH head (years)	36.39	1.16	0.55	-0.61	339
	(14.61)	(3.21)	(1.76)	(1.94)	
HH head finshed primary school	0.22	0.10	0.08	-0.02	342
	(0.43)	(0.11)	(0.06)	(0.07)	
HH size	7.17	-0.03	0.24	0.48	342
	(3.43)	(0.81)	(0.44)	(0.49)	
Number of bedrooms	2.22	0.07	-0.13	0.10	342
	(1.26)	(0.29)	(0.16)	(0.17)	
Access to extension last year	0.22	-0.08	-0.06	0.00	342
	(0.43)	(0.07)	(0.04)	(0.04)	
Has used fertilizer last season	0.22	-0.01	-0.03	0.07	342
	(0.43)	(0.09)	(0.05)	(0.06)	
Has used improved seed last season	0.28	0.06	0.02	0.02	342
	(0.46)	(0.11)	(0.06)	(0.07)	
Distance nearest agro input shop (km)	5.72	0.24	-0.84	0.25	342
	(5.36)	(1.21)	(0.66)	(0.73)	
HH owns mobile phone	0.72	-0.02	0.05	0.04	342
	(0.46)	(0.10)	(0.06)	(0.06)	
HH has access to a mobile phone	0.83	-0.08	0.06	0.00	342
	(0.38)	(0.10)	(0.05)	(0.06)	
F-test		0.546	1.058	1.035	
P-value		0.872	0.395	0.415	

Note: First column reports control group means (and standard deviations below); Column 2 reports differences between placebo and video treatment (and standard error below), column 3 between video only and video+ivr, column 4 between video+ivr and video+ivr+SMS. N is sample size.

Table A.2: Impact of dissemination technologies on knowledge (conditional on access to mobile phone)

	Mean	+IVR	p-value	N	+SMS	p-value	N
Knows optimal spacing (yes=1)	0.174	-0.015	0.392	3,002	0.002	0.941	2,736
	(0.380)	(0.020)			(0.022)		
Knows inputs best combined (yes=1)	0.905	-0.013	0.173	3,002	0.005	0.699	2,736
	(0.293)	(0.011)			(0.012)		
Knows optimal time for weeding (yes=1)	0.945	0.003	0.742	3,002	0.007	0.618	2,736
	(0.228)	(0.011)			(0.012)		
Knows how to fight armyworm (yes=1)	0.338	-0.009	0.690	3,002	0.008	0.720	2,736
	(0.474)	(0.021)			(0.023)		
Knowledge index	-0.109	-0.023	0.317	3,002	0.018	0.613	2,736
	(0.610)	(0.027)			(0.030)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3 and number of observations in column 4; column 5 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 6; sample size is reported in column 7. Reported p-values are based on randomization inference (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

Table A.3: 2SLS estimates of impact of dissemination technologies on household level knowledge

	Mean	+IVR	p-value	+SMS	p-value	N
Knows optimal spacing (yes=1)	0.160	-0.360	0.306	0.014	0.596	3,619
	(0.367)	(0.351)		(0.026)		
Knows inputs best combined (yes=1)	0.908	-0.331	0.115	0.014	0.379	3,619
	(0.290)	(0.210)		(0.015)		
Knows optimal time for weeding (yes=1)	0.954	0.178	0.350	0.000	0.979	3,619
	(0.210)	(0.191)		(0.015)		
Knows how to fight armyworm (yes=1)	0.336	-0.286	0.431	0.023	0.401	3,619
	(0.473)	(0.363)		(0.028)		
Knowledge index	-0.077	-0.396	0.376	0.026	0.458	3,619
	(0.562)	(0.473)		(0.036)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 5; sample size is reported in column 6. All specifications control for the other orthogonal factors in the factorial design.

Table A.4: Impact of IVR and SMS on agronomic practices (conditional on phone phone access)

	Mean	+IVR	p-value	N	+SMS	p-value	N
Planted immediately after start of rains (yes=1)	0.365	0.013	0.559	2,924	-0.020	0.433	2,673
	(0.483)	(0.022)			(0.024)		
Used spacing of 75cm x 30cm with a reduced seed rate (yes=1)	0.030	-0.011	0.360	2,962	0.014	0.331	2,707
	(0.171)	(0.013)			(0.014)		
Removed striga early on (yes=1)	0.690	-0.003	0.867	2,962	0.021	0.376	2,707
	(0.464)	(0.020)			(0.022)		
First weeding after 18-20 days (yes=1)	0.435	0.019	0.331	2,962	0.002	0.950	2,707
	(0.497)	(0.023)			(0.025)		
Recommended practices index	-0.088	0.008	0.685	2,924	0.014	0.584	2,673
	(0.482)	(0.024)			(0.026)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3 and number of observations in column 4; column 5 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 6; sample size is reported in column 7. Reported p-values are based on randomization inference (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

Table A.5: 2SLS estimates of impact of dissemination technologies on agronomic practices

	Mean	+IVR	p-value	+SMS	p-value	N
Planted immediately after start of rains (yes=1)	0.370	0.163	0.677	-0.002	0.940	3,500
	(0.484)	(0.391)		(0.029)		
Used spacing of 75cm x 30cm with a reduced seed rate (yes=1)	0.026	-0.089	0.670	0.020	0.231	3,560
	(0.158)	(0.210)		(0.017)		
Removed striga early on (yes=1)	0.685	-0.170	0.617	0.033	0.215	3,560
	(0.465)	(0.339)		(0.027)		
First weeding after 18-20 days (yes=1)	0.426	0.228	0.552	-0.012	0.693	3,560
	(0.495)	(0.383)		(0.030)		
Recommended practices index	-0.086	0.102	0.804	0.028	0.364	3,500
	(0.478)	(0.411)		(0.031)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 5; sample size is reported in column 6. All specifications control for the other orthogonal factors in the factorial design.

Table A.6: Impact of IVR and SMS on fertilizer and improved seed use (conditional on access to mobile phone)

	Mean	+IVR	p-value	N	+SMS	p-value	N
			fertilizer use				
Used DAP/NPK on at least one plot? (yes=1)	0.285	0.029	0.095	2,962	-0.022	0.408	2,707
	(0.453)	(0.020)			(0.022)		
Used urea on at least one plot? (yes=1)	0.050	0.013	0.288	2,962	-0.031	0.050	2,707
	(0.218)	(0.014)			(0.015)		
Used organic fertilizer on at least one plot? (yes=1)	0.150	-0.044**	0.011	2,962	0.037	0.083	2,707
	(0.358)	(0.019)			(0.021)		
Fertilizer index	-0.074	-0.002	0.908	2,962	-0.015	0.675	2,707
	(0.531)	(0.027)			(0.029)		
			seed use				
Used hybrid maize seed on at least one plot? (yes=1)	0.330	0.023	0.234	2,962	-0.053	0.028*	2,707
	0.471	0.021			0.023		
Used Open Polinated Varieties on at least one plot? (yes=1)	0.275	0.011	0.543	2,962	0.026	0.386	2,707
	0.448	0.021			0.023		
Seed index	0.010	0.038	0.161	2,962	-0.026	0.475	2,707
	0.701	0.030			0.033		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3 and number of observations in column 4; column 5 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 6; sample size is reported in column 7. Reported p-values are based on randomization inference (10,000 permutations); ** and * denote that the difference is signficant at the 5 and 10 percent level, respectively, after correcting for multiple hypothesis testing using a family-wise sharp null (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

Table A.7: 2SLS estimates of impact of dissemination technologies on fertilizer and improved seed use

	Mean	+IVR	p-value	+SMS	p-value	N
			fertilizer use			
Used DAP/NPK on at least one plot? (yes=1)	0.264	0.393	0.228	-0.011	0.661	3,560
	(0.442)	(0.325)		(0.025)		
Used urea on at least one plot? (yes=1)	0.051	0.225	0.320	-0.030	0.092	3,560
	(0.221)	(0.226)		(0.018)		
Used organic fertilizer on at least one plot? (yes=1)	0.157	-0.704	0.037	0.044	0.077	3,560
	(0.365)	(0.337)		(0.025)		
Fertilizer index	-0.057	-0.078	0.846	-0.003	0.994	3,560
	(0.547)	(0.443)		(0.035)		
			seed use			
Used hybrid maize seed on at least one plot? (yes=1)	0.289	0.732	0.046	-0.063	0.022	3,560
	(0.454)	(0.367)		(0.027)		
Used Open Polinated Varieties on at least one plot? (yes=1)	0.302	0.164	0.635	0.033	0.220	3,560
	(0.460)	(0.345)		(0.027)		
Seed index	0.032	0.242	0.605	0.004	0.876	3,560
	(0.700)	(0.447)		(0.036)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3 and number of observations in column 4; column 5 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 6; sample size is reported in column 7. Reported p-values are based on randomization inference (10,000 permutations); ***, ** and * denote that the difference is signficant at the 1, 5 and 10 percent level, respectively, after correcting for multiple hypothesis testing using a family-wise sharp null (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

Table A.8: Impact of IVR and SMS on household level production (conditional on access to mobile phone)

	Mean	+IVR	p-value	N	+SMS	p-value	N
Maize production (log(kg)) 5.921	0.057	0.146	2,742	-0.001	0.894	2,511	
(0.706)	(0.036)			(0.039)			
Maize area (log(acre)) 0.054	-0.018	0.492	2,782	0.004	0.997	2,545	
(0.554)	(0.029)			(0.031)			
Maize yield (log(kg/acre)) 5.879	0.042	0.203	2,756	0.011	0.737	2,518	
(0.654)	(0.031)			(0.034)			
Yield better than normal (yes=1) 0.405	-0.005	0.812	2,962	0.036	0.166	2,707	
(0.492)	(0.023)			(0.024)			
Labour(log(mandays)) 4.157	-0.009	0.729	2,802	0.021	0.515	2,549	
(0.571)	(0.027)			(0.028)			
Labour productivity (log(kg/mandays)) 1.673	0.060	0.082	2,780	-0.012	0.672	2,543	
(0.708)	(0.036)			(0.039)			
Production index -0.052	0.016	0.306	2,756	0.009	0.572	2,518	
(0.378)	(0.017)			(0.018)			

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3 and number of observations in column 4; column 5 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 6; sample size is reported in column 7. Reported p-values are based on randomization inference (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

Table A.9: 2SLS estimates of impact of dissemination technologies on production

	Mean	+IVR	p-value	+SMS	p-value	N
Maize production (log(kg))	5.814	0.912	0.173	0.054	0.276	3,344
	(0.765)	(0.670)		(0.050)		
Maize area (log(acre))	0.018	-0.240	0.614	0.031	0.415	3,341
	(0.580)	(0.476)		(0.038)		
Maize yield (log(kg/acre))	5.850	0.690	0.224	0.005	0.898	3,302
	(0.658)	(0.568)		(0.041)		
Yield better than normal (yes=1)	0.387	0.008	0.983	0.048	0.103	3,560
	(0.488)	(0.374)		(0.030)		
Labour(log(mandays))	4.132	-0.056	0.895	0.037	0.296	3,370
	(0.577)	(0.421)		(0.036)		
Labour productivity (log(kg/mandays))	1.650	1.185	0.076	0.000	0.996	3,341
	(0.720)	(0.667)		(0.048)		
Production index	-0.053	0.159	0.625	0.007	0.702	3,302
	(0.365)	(0.297)		(0.022)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 5; sample size is reported in column 6. All specifications control for the other orthogonal factors in the factorial design.

Table A.10: Impact of IVR and SMS on maize disposal (conditional on access to mobile phone)

	Mean	+IVR	p-value	N	+SMS	p-value	N
Consumed maize (yes=1)	0.845	-0.017	0.283	3,000	0.002	0.919	2,734
	(0.363)	(0.015)			(0.016)		
Sold maize (yes=1)	0.650	0.003	0.910	2,966	0.005	0.833	2,708
	(0.478)	(0.022)			(0.024)		
Saved maize for seed (yes=1)	0.854	-0.017	0.305	2,937	0.007	0.745	2,681
	(0.354)	(0.018)			(0.020)		
Disposal index	-0.068	0.006	0.802	2,935	-0.004	0.923	2,679
	(0.498)	(0.025)			(0.028)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3 and number of observations in column 4; column 5 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 6; sample size is reported in column 7. Reported p-values are based on randomization inference (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

Table A.11: 2SLS estimates of impact of dissemination technologies on maize disposal

	Mean	+IVR	p-value	+SMS	p-value	N
Consumed maize (yes=1)	0.835	-0.055	0.840	0.012	0.567	3,617
	(0.372)	(0.271)		(0.021)		
Sold maize (yes=1)	0.643	0.035	0.924	-0.014	0.624	3,569
	(0.480)	(0.367)		(0.029)		
Saved maize for seed (yes=1)	0.854	-0.436	0.160	0.024	0.318	3,533
	(0.354)	(0.311)		(0.024)		
Disposal index	-0.059	0.449	0.293	-0.023	0.496	3,531
	(0.510)	(0.423)		(0.034)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 5; sample size is reported in column 6. All specifications control for the other orthogonal factors in the factorial design.

Table A.12: Impact of IVR and SMS on household welfare (conditional on phone phone access)

	Mean	+IVR	p-value	N	+SMS	p-value	N
Is your household better off than average? (yes=1)	0.425	-0.025	0.254	3,000	0.012	0.629	2,734
	(0.496)	(0.023)			(0.025)		
Is your household better off than 6 months ago? (yes=1)	0.430	-0.037	0.075	3,000	0.049	0.112	2,734
	(0.496)	(0.022)			(0.024)		
Is able to eat preferred food? (yes=1)	0.440	-0.001	0.948	3,000	0.008	0.746	2,734
	(0.498)	(0.022)			(0.024)		
Is able to eat enough food? (yes=1)	0.605	-0.012	0.614	3,000	0.025	0.318	2,734
	(0.490)	(0.023)			(0.024)		
Consumption expenditure (log)	10.934	0.014	0.726	2,840	-0.047	0.138	2,591
	(0.549)	(0.025)			(0.027)		
Welfare index	0.026	-0.030	0.283	2,840	0.009	0.740	2,591
	(0.578)	(0.027)			(0.030)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3 and number of observations in column 4; column 5 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 6; sample size is reported in column 7. Reported p-values are based on randomization inference (10,000 permutations). All specifications control for the other orthogonal factors in the factorial design.

Table A.13: 2SLS estimates of impact of dissemination technologies on household welfare

	Mean	+IVR	p-value	+SMS	p-value	N
Is your household better off than average? (yes=1)	0.397	-0.451	0.252	0.025	0.405	3,617
	(0.490)	(0.394)		(0.030)		
Is your household better off than 6 months ago? (yes=1)	0.388	-0.494	0.208	0.054	0.065	3,617
	(0.488)	(0.392)		(0.029)		
Is able to eat preferred food? (yes=1)	0.418	0.155	0.685	0.021	0.485	3,617
	(0.494)	(0.382)		(0.029)		
Is able to eat enough food? (yes=1)	0.591	0.051	0.894	0.036	0.223	3,617
	(0.493)	(0.388)		(0.030)		
Consumption expenditure (log)	10.924	0.164	0.705	-0.049	0.150	3,423
	(0.568)	(0.432)		(0.034)		
Welfare index	0.032	-0.259	0.587	0.013	0.642	3,423
	(0.582)	(0.470)		(0.037)		

Note: In the first column, means (and standard deviations) in the comparison group are presented for each variable. Column 2 reports differences between video only and video+ivr (and standard error) with its corresponding p-value in column 3; column 4 reports differences between video+ivr and video+ivr+SMS (and standard error) with its corresponding p-value in column 5; sample size is reported in column 6. All specifications control for the other orthogonal factors in the factorial design.