REVIEW SUMMARY

AGRICULTURE

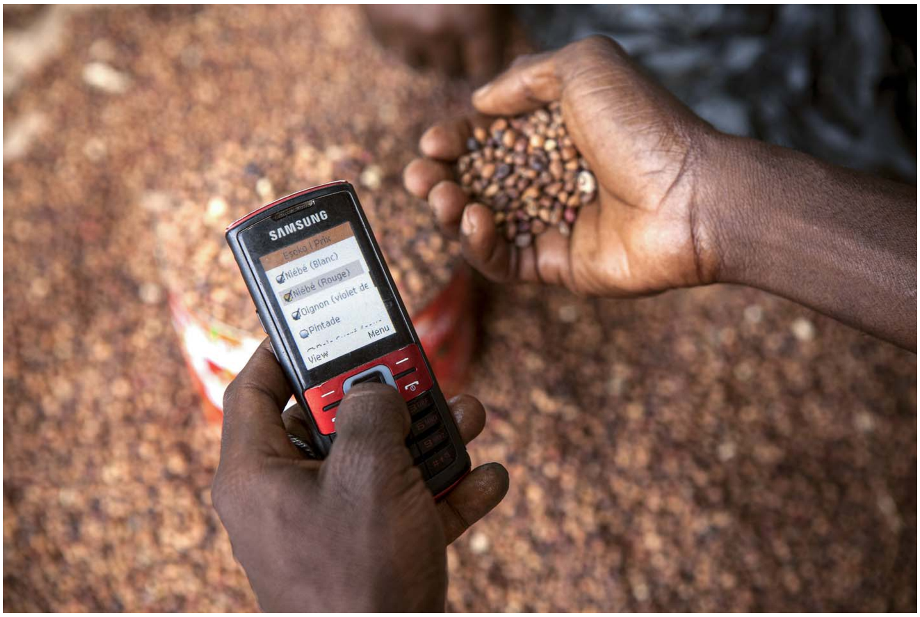
Realizing the potential of digital development: The case of agricultural advice

Raissa Fabregas, Michael Kremer, Frank Schilbach*

BACKGROUND: Sustainably raising agricultural productivity for the 2 billion people living in smallholder farming households in the developing world is critical for reducing world poverty and meeting rising food demand in the face of climate change. Nevertheless, most smallholder farmers have no access to science-based agricultural advice. The widespread adoption of basic mobile phone technology presents opportunities to improve upon existing in-person agricultural extension efforts that are expensive and fraught with accountability problems.

ADVANCES: Meta-analyses suggest that the transmission of agricultural information through mobile technologies in sub-Saharan Africa and India increased yields by 4% and the odds of adoption of recommended agrochemical inputs by 22%. The delivery of market information can have additional system-wide impacts, reducing price dispersion and lowering transaction costs. Given the low and rapidly declining cost of information transmission, benefits likely exceed costs by an order of magnitude. Even basic phones and inexpensive text and voice messages can influence farmer behavior. Smartphones with GPS systems create the potential for larger gains through the transmission of more sophisticated media, such as videos, and for locally customized information on soil characteristics, weather, and pest outbreaks, delivered at the appropriate time during the agricultural season.

Messages could be customized on the basis of farmer characteristics, such as education or financial circumstances. Experimentation, machine learning, and two-way communication with and between farmers could facilitate improvements of information and other services over time. Advances from behavioral science can improve information transmission and address behavioral barriers to the adoption of improved agricultural techniques. Mobile phone–based systems could increase the productivity and accountability of in-person extension agents and enhance supply chain functionality. Realizing the potential of digital agriculture will require an interdisciplinary effort to develop and rigorously test a variety of approaches, incorporating insights from behavioral science, agriculture, economics, and data science.



Mobile phones can benefit farmers in low- and middle-income countries by improving access to agricultural advice and market price information. Mobile technologies, particularly smartphones, have the potential to bring sophisticated science-based agricultural advice to smallholder farmers to improve productivity, especially under rapidly changing economic and environmental conditions. However, market failures likely preclude efficient scaling of valuable digital advice applications.

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OUTLOOK: Multiple market failures associated with information markets limit the ability of mobile phone–based extension systems to reach socially efficient scale through purely commercial financing. Because the marginal costs of disseminating information are close to zero, the optimal scale of such systems is very large. However, fixed system development costs still must be covered. Multiple organizations have introduced digital agricultural extension systems with financial models based on selling subscriptions to individual farmers, but such systems have been able to reach only a small fraction of farmers in the developing world. Farmer payments may be insufficient to cover the fixed costs, because information is difficult to exclude from nonpurchasers and because it is challenging for farmers to verify the quality of the information. Existing evidence suggests substantial gaps between farmers' willingness to pay for information and its social value. Advertising or agrochemical input sales could be used to finance information provision, but this approach could incentivize providers to distort information content in the absence of strong reputational costs of misinformation or appropriate regulation.

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Public financing could cover fixed costs and enable scale-up. Although agriculture ministries often deliver messages in ways that farmers find difficult to understand and use, recent examples suggest that if feedback mechanisms are in place, governments can improve their services over time. Models that incentivize farmers to share their experiences create scope for customization and efficiency gains as systems grow, because this data may be used to improve recommendations for other farmers. If successful, digital agricultural advisory systems could supply a model for digital development more broadly. ■

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REVIEW

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Realizing the potential of digital development: The case of agricultural advice

Raissa Fabregas[1], **Michael Kremer**[2], **Frank Schilbach**[3]*

The rapid spread of mobile phones creates potential for sustainably raising agricultural productivity for the 2 billion people living in smallholder farming households. Meta-analyses suggest that providing agricultural information via digital technologies increased yields by 4% and the odds of adopting recommended inputs by 22%. Benefits likely exceed the cost of information transmission by an order of magnitude. The spread of GPS-enabled smartphones could increase these benefits by enabling customized information, thus incentivizing farmers to contribute information to the system. Well-known distortions in markets for information limit the ability of such systems to reach the socially efficient scale through purely commercial means. There is a clear role for public support for digital agricultural extension, but messages designed by agricultural ministries are often difficult for farmers to understand and use. Realizing the potential of mobile communication systems requires feedback mechanisms to enable rigorous testing and continuous improvement.

Mobile phones have penetrated the developing world to a greater extent than most other technologies (Fig. 1). More than three of four people in low- and middle-income countries (LMICs) own a phone. Approximately one in three people have internet access, and access is expected to increase markedly as smartphone costs decline (*1*).

The spread of phones presents opportunities for digital development by reducing information acquisition costs, allowing customization of information, and enabling monitoring and accountability in public services (*1*–*3*). Digital technologies have been deployed in a range of sectors—including finance, education, health, and civic participation—to improve development outcomes (*1*, *4*, *5*).

The proliferation of phones may also carry risks, such as the potential to exacerbate violent conflict (*6*), enable state surveillance and propaganda (*7*), accelerate the spread of fake news via social media, or further widen inequality because of uneven access to digital technologies (*8*, *9*). Finance and governance systems will affect the sustainability, scale, equitable reach, and effective design and implementation of these systems.

We review the evidence on “digital agriculture.” With current technologies, impacts on farming practices and yields are modest in absolute terms but large relative to the cost of information delivery. The spread of GPS-enabled smartphones will create opportunities for customization and two-way communication, but an interdisciplinary effort will be required to experiment with different approaches and rigorously measure impact. Distortions in the markets for information limit the ability of systems to reach the socially efficient scale through purely commercial means, such that scaling programs beyond their current modest levels will likely involve an active public-sector role.

Traditional agricultural extension

Raising agricultural productivity is critical to reducing poverty and satisfying the growing global food demand (*10*) in the face of environmental stress and climate change. Improved access to agricultural information and targeting of agricultural inputs can raise agricultural productivity and reduce negative environmental footprints (*11*, *12*).

Nevertheless, most smallholder farmers lack access to science-based agricultural advice. Although ~400,000 agricultural extension agents (*13*) are employed by governments in LMICs, the ratio of farmers to extension workers exceeds 1000 to 1 in many countries (*14*). Transport budgets are often meager, and training, management, and accountability of extension workers are inadequate. In India, only 6% of farmers report having received any advice from an extension agent in the past year, and 70% of farmers distrust extension worker recommendations (*15*).

More generally, there is limited evidence of extension services’ impact or cost effectiveness (*13*, *16*). Extension workers have been found to favor their own social networks (*17*) and neglect the most vulnerable farmers (*18*, *19*) and women (*20*, *21*).

Digital agriculture: Potential and challenges

There is good reason to believe that emerging digital technologies can improve the functioning of agriculture markets at a very low cost per farmer. Establishing initial mobile phone coverage involves fixed costs, but the marginal cost of phone communication in rural areas is close to zero because cell phone towers typically operate below capacity. Cellular phone companies charge prices well above marginal cost, but they are often highly regulated, and governments could negotiate access at prices with lower markups.

Mobile phones, particularly GPS-enabled smartphones, facilitate the provision of tailored information. Recommendations for agrochemical inputs that address specific soil conditions on the basis of digital maps can improve yields while reducing environmentally harmful and wasteful use (*22*–*24*). Messages can target specific areas with reported pest outbreaks or be customized to other local conditions such as market prices. Farmers can tailor their investment decisions to expected weather patterns and benefit from improvements in weather forecasting (*25*, *26*). Customized information allows farmers to choose language, dialect, or literacy levels. Mobile technologies can also provide reminders and other nudges to address behavioral biases (*27*).

Running these systems at scale allows for testing variations to establish the most effective approaches (A/B testing) and feedback loops to improve accuracy and effectiveness of messages over time. Images taken from satellites can provide rich data about crop growth and, when linked with Geographic Information System (GIS) on plot boundaries, can improve measurements of productivity at scale and allow for ongoing experimentation (*28*, *29*). Mobile phones facilitate two-way communication, whereby farmers can ask questions and request information. Such platforms can also provide opportunities for networking and information exchange among farmers. Information from farmers using the system can further improve future recommendations for all users.

As smartphone use continues to expand, farmers will increasingly have the means to watch videos demonstrating new agricultural techniques or take pictures of pests affecting their crops and either request automatic identification and recommendations or raise questions with agronomists (*30*). Smartphones may also provide farmers access to interventions and apps that can enhance psychological well-being (*31*). Increased aspirations, grit, and improved mental health may boost farmer income by increasing investment and facilitating learning among farmers (*32*–*34*).

Mobile phones may create opportunities to complement and strengthen existing in-person

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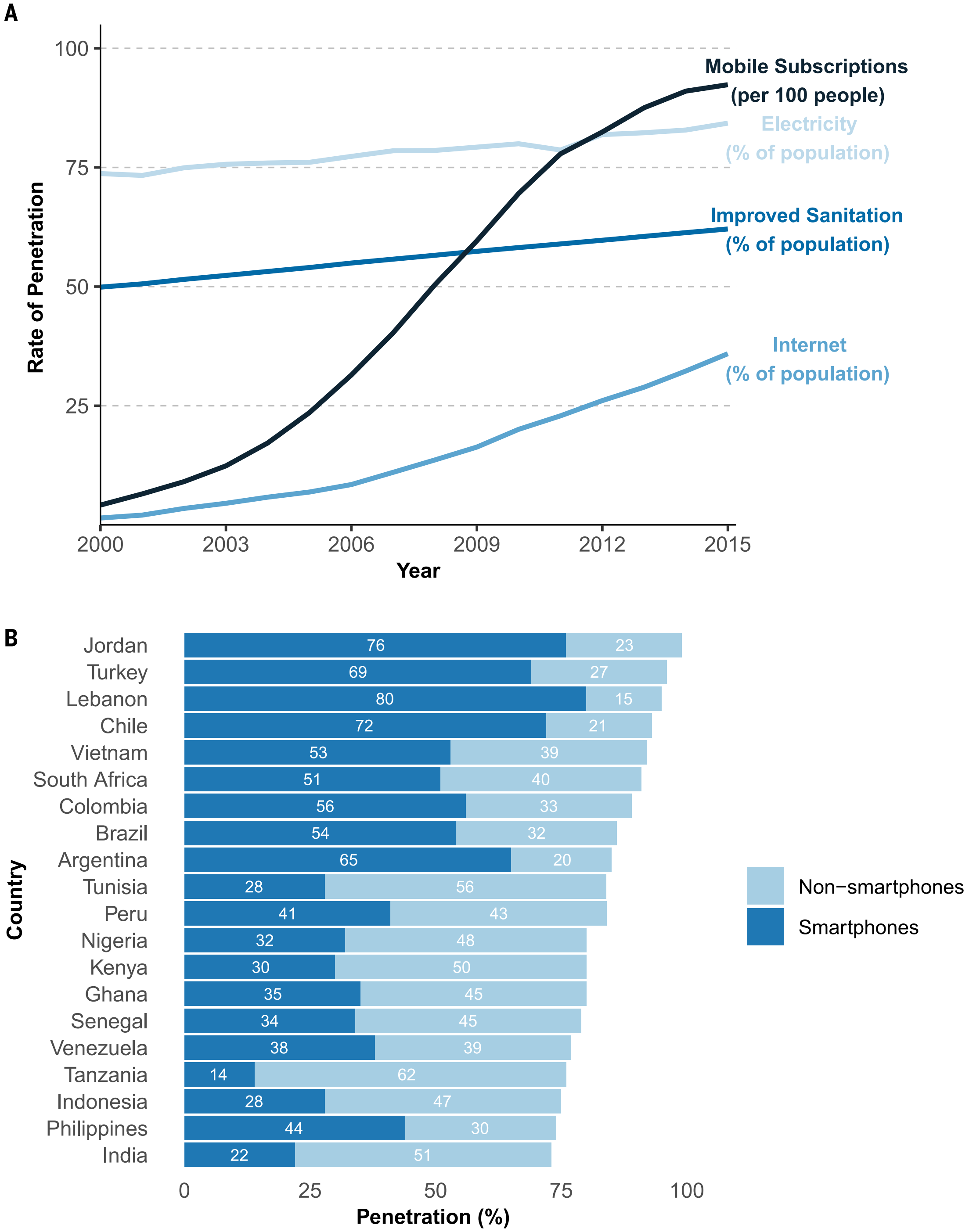

Fig. 1. The spread of mobile phones in LMICs. (**A**) Growth of mobile phone subscriptions relative to other services in LMICs. "Improved sanitation" denotes the percentage of people using basic sanitation services, at minimum [data from (*1*) and World Development Indicators: https://datacatalog.worldbank.org/dataset/world-development-indicators]. (**B**) Mobile phone penetration, as determined by the percentage of adults who report owning any mobile phone and those who own a smartphone [data from Pew Global Attitudes Survey, Spring 2017: www.pewresearch.org/global/dataset/spring-2017-survey-data/].

agricultural extension efforts. Many agricultural extension workers already have smartphones and thus could download information on pests, flooding, or other problems arising in their region, as well as information needed to respond to farmer queries. Automatic notifications can allow extension agents to alert farmers in their region when they are visiting demonstration plots or conducting training sessions. Mobile phones could also be used to improve accountability among extension workers—for example, by allowing extension workers and their supervisors to set goals and track performance, enabling automatic collection of feedback from farmers, or tracking whether extension agents actually visit farmers.

Finally, digital agricultural services can improve the functioning of agricultural supply chains. For example, these services could make it easier for farmers to check and compare input or output prices, potentially lowering markups; notify farmers whether inputs are in stock with particular dealers; and facilitate coordination among farmers in an area and

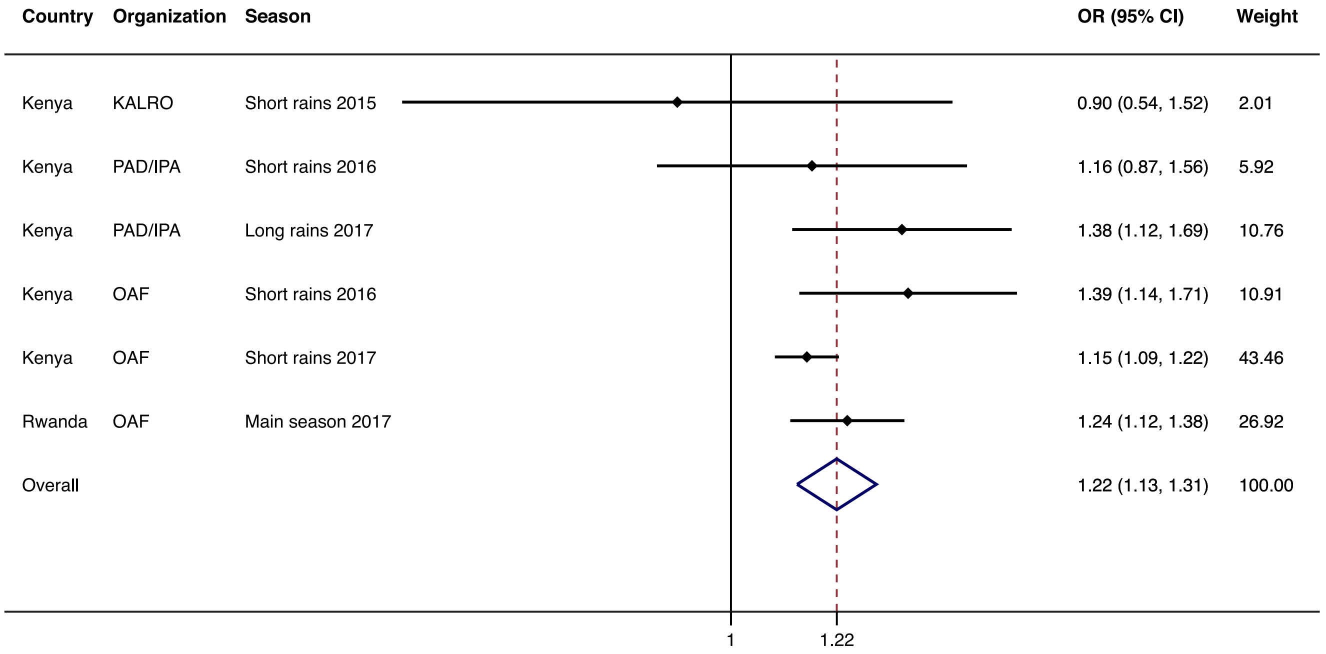

Fig. 2. Effects of text messages on acquisition of recommended inputs. Meta-analysis of the effects of text messages on following advice for purchasing agricultural lime, as measured by administrative data. Kenya Agriculture and Livestock Research Organization (KALRO), Precision Agriculture for Development and Innovations for Poverty Action (PAD/IPA), and One Acre Fund (OAF) implemented the programs. The effects are measured in odds ratios (OR). The OR is the ratio of the odds of following recommendations in the treatment group divided by the odds in the control group. The odds refer to the probability of following the advice over the probability of not following the advice. Weights are from a random effects analysis [data adapted from (*47*)].

with traders. Firms could use projections of harvest quality to inform lending decisions (*35*). Satellite-based yield assessment could be used to inform social insurance programs that provide support for farmers in response to weather or pest disasters.

However, despite the potential of digital agriculture advisory services, reasons for skepticism remain. Overcoming informational constraints may not result in substantially increased agricultural productivity, given the existence of other barriers such as credit constraints, input shortages at local markets, and missing insurance markets and infrastructure (*12*). Even to the extent that informational barriers are important, mobile phone messages may not overcome them: Some farmers ignore messages, especially from unknown sources, because phone spam is common in many LMICs. Some farmers are illiterate and have difficulty using voice menus. Senders may design obscure and confusing messages or may provide messages designed to target objectives at odds with farmer interests, such as messages aimed at increasing sales of inappropriate agricultural inputs. Certain kinds of information may be too complicated to convey by text or voice; effective communication may require pictures or video. Smartphones are thus required to receive these messages, but few smallholder farmers currently have access to this technology in the poorest countries. Finally, farmers may begin to ignore reminders or nudges if they are repeated too often, or they may be annoyed by unwanted spam messages or feel patronized by reminders and exhortations (*36*). Taken together, such issues could lead to reduced trust in the messaging system.

Realizing the potential of customization and two-way communication in LMICs carries particular challenges. Customization requires information about a farm's location, which is difficult to collect remotely unless farmers have GPS-enabled smartphones, because in many countries there is a lack of precisely-defined physical addresses (*37*), area names are often ambiguous, and user text entry is error prone (*38*). Gathering agricultural data from farmers is challenging because response rates to phone surveys are typically low; farmers may be hesitant to provide accurate information; and some information, such as exact yields, can be difficult to quantify.

Impacts of digital agriculture: Empirical evidence

Earlier reviews of the impacts of digital agricultural extension report mixed results and considerable context dependence (*39*–*43*). However, sufficient evidence is now emerging to begin quantitatively assessing the farmer-level impact of digital agricultural extension by meta-analysis.

Impacts on individual farmers

Several experimental studies have found that mobile phone–based programs increase farmer knowledge and self-reported adoption or planned adoption of recommended agricultural inputs and practices (*44*–*46*). Each of these outcome variables has limitations. Knowledge may or may not translate into behavior change. Relying on self-reported data on the use of inputs may lead to overestimation of impact. For example, farmers who receive messages advocating certain behavior may over-report this behavior because of social desirability bias. Indeed, a recent meta-analysis of four trials in Kenya found that the measured impact of mobile phone messages using self-reported data exceeded the impacts based on administrative data (*47*).

To alleviate such concerns, administrative data on input purchases from agricultural suppliers or redemption of discount coupons were used to measure farmer behavior in six experimental evaluations of text messaging programs that encouraged farmers in East Africa to use locally appropriate inputs (*47*). Figure 2 depicts the results from a meta-analysis of these studies, which found that the odds ratio for following the recommendation to purchase agricultural lime, an input to reduce soil acidity, is 1.22 [95% confidence interval (CI): 1.13 to 1.31]. For context, the proportion of people acquiring recommended inputs in each of the control groups ranged from 0.03 to 0.32.

Some of the individual experiments had statistically significant impacts and others did not. However, we cannot reject the hypothesis that the effects were the same across

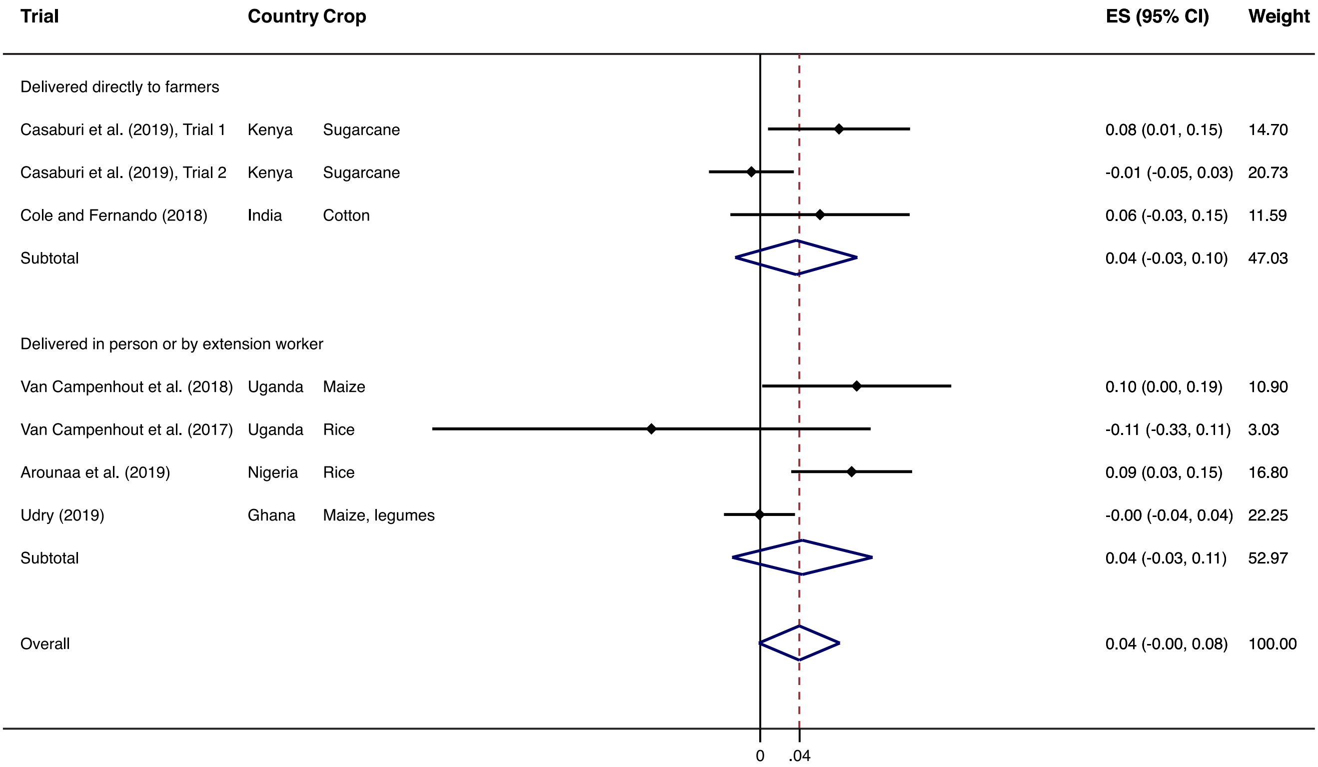

Fig. 3. Effects of digital agriculture programs on yields. Meta-analysis of effects of digital technologies on crop yields drawn from six studies that report yields [data from (*46*, *48*–*52*)]. For the study by Udry (*52*), the outcome variable is harvest value. The upper portion of the figure shows the impact of mobile-based programs delivered directly to farmers. The lower portion shows the impact of digital programs with an in-person component. Weights are from a random effects analysis. ES, effect size as a percentage increase.

contexts and that the estimated effects differed only because of sampling variation, which suggests that we need to be cautious in claims regarding heterogeneous treatment effects and, in particular, in interpreting the sources of differences in estimated effects across studies. Combining these estimates with agricultural trial data on the impact on yields of treating soil with lime suggests that farm profits increased by one to two orders of magnitude beyond the marginal cost of sending the messages. Similar estimates were found for fertilizer purchases (*47*).

Figure 3 reports on a complementary meta-analysis measuring the impact of experimentally evaluated digital agricultural extension interventions on farm yields or harvest value (unfortunately we do not have sufficient data on farm costs to estimate impacts on profits). This analysis encompasses four trials of messages delivered purely through mobile phones: two text message interventions with sugarcane farmers in Kenya (*48*) and two season measures for an interactive voice response (IVR) intervention with cotton farmers in India (*46*). It also includes four studies with an in-person component: two video interventions with maize and rice farmers in Uganda implemented via in-person visits (*49*, *50*), a program providing customized information on rice cultivation to Nigerian farmers offered through extension workers (*51*), and a program in Ghana delivered by community extension workers who relied on a mobile software application (*52*).

Several statistical approaches indicate that digitally delivered advice to farmers increases yields by ~4% (see supplementary materials). Notably, the impacts are not larger for services that include more costly in-person components. On average, the value of increased output greatly exceeds the marginal cost of delivery via mobile phones, such that policy-makers would invest in mobile-based programs unless they are highly risk-averse.

Several factors suggest that the true returns to investment in digital agricultural extension may be higher than these numbers suggest. First, farmers who receive information via digital agricultural extension sometimes transmit it to other farmers, thus creating additional benefits (*46*, *47*). Second, to the extent that impacts vary across contexts and policy-makers have data to assess impact in their own context, there is value in testing such systems, assessing their effects, and adjusting policy accordingly. Unsuccessful programs can be abandoned and successful ones scaled up. Finally, impacts are likely to improve over time as farmers learn to use the systems, program operators improve message content and delivery through A/B trials, and smartphone use spreads, enabling digital extension services to incorporate more advanced technology, such as video, and better customization to local conditions. Video-based interventions and a gamified app have also been found to improve knowledge and farmers' practices (*30*, *50*, *53*, *54*).

As noted, traditional in-person agricultural extension has been found to favor certain groups. It seems likely that digital extension will also favor men, as well as richer, younger, and more educated farmers with better digital access. However, current data are inconclusive, and it is possible that biases will be less severe than with in-person extension. Cole and Fernando (*46*) report suggestive evidence that richer farmers were modestly more engaged in the service they studied and were more likely to adopt recommended practices. In contrast, Fabregas *et al.* (*47*) found little evidence of heterogeneous impact in their meta-analysis, although the underlying studies did not include farmers without phones.

Market- or system-level impacts

Beyond individual-level effects, digital technologies can also affect farmers by altering entire markets or systems. In particular, improved access to price information can enable farmers to sell their products in markets with higher prices and reduce price dispersion across markets. By reducing waste of perishable goods and the need for middlemen,

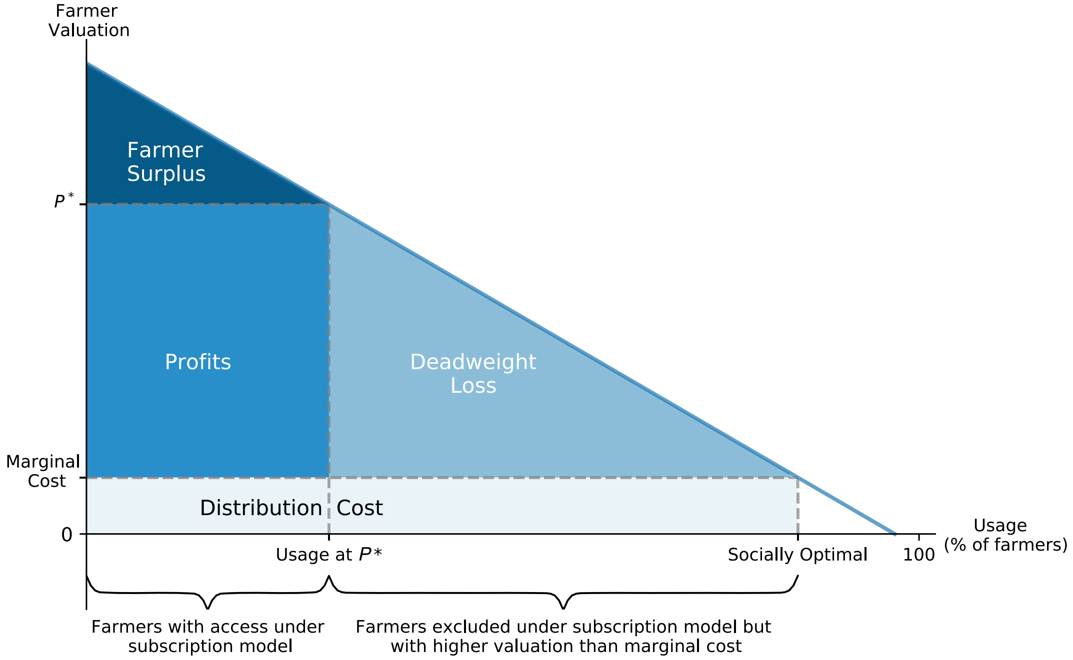

Fig. 4. Farmer valuation curve and usage under a subscription model. Given the downward-sloping valuation (or demand) curve, P^* is the profit-maximizing price. Usage at this price is lower than the socially efficient level, giving rise to a deadweight loss. Firms would not be able to cover fixed costs if they set prices at the distribution costs. Firms will invest in a system only if the development costs are less than the expected profits, whereas a hypothetical benevolent social planner would invest as long as costs are less than the sum of profits, farmer surplus, and deadweight loss.

improved information access can thus increase producer prices and lower average prices for consumers. Access to mobile phones allowed Indian fishermen to compare prices while still at sea and then transport their catch to the markets offering the highest prices, thus causing a reduction in price dispersion across markets (*55*). Fewer fish were wasted, profits increased by 8%, and consumer prices declined by 4%.

Studies in Uganda and Niger recorded similar results for other crops (*56*–*58*); delivering price information for staple grains was also found to cause positive effects in Ghana and Peru (*59*, *60*). In contrast, sending farmers price and weather information through text messages and phone calls did not affect average prices for crops from farmers in India or Colombia (*61*–*63*). These differences are hypothesized to result from a combination of factors, including differences in target populations, crop varieties, the importance of informational constraints, message design, and barriers to the effective use of information and communications technology (*41*).

Digital technologies may also improve supply chains by helping farmers shop for adequate inputs or report inefficiencies or fraud. Casaburi *et al.* (*64*) examined a contract-farm setting in which farmers sign contracts with a sugar company in Kenya. The company provides agrochemical inputs to farmers and then deducts the costs of the inputs from the amount it pays farmers for the sugarcane. Delays or failures in fertilizer deliveries to farmers are common, but by establishing a hotline for farmers to report problems, late delivery was reduced by 23% and nondelivery by 54%. The benefits spill over to neighbors because the company schedules deliveries to neighboring farms at the same time.

An important area for future work is exploring whether digital agriculture can address supply chain problems, such as limited competition and high markups (*65*) and adulteration and counterfeiting of inputs (*66*). Moreover, studying the distributional effects of different interventions, arising from a combination of the direct effects of receiving digital advice itself and through positive or negative spillovers of interventions, remains a fruitful area for investigation.

Learning from farmers

A key open empirical question is the extent to which mobile systems can gather valuable information from farmers, which in turn can be used to inform other farmers. In the United States, Farmers Business Network applies machine learning to hundreds of thousands of acre-years of data to provide high-quality yield predictions for seed varieties (*67*). Mobile phone systems in LMICs could potentially be used to collect data to serve as inputs in machine learning applications, learn from farmers' experiences with particular agricultural technologies, and facilitate networking among farmers.

However, gathering high-quality data from farmers is challenging. At the most basic level, phone surveys allow collection of high-frequency survey data on agricultural production at a much lower cost than traditional methods (*68*). Yet despite some successes in eliciting information through phone-based feedback tools (*69*), phone surveys are plagued with low response rates and thus may be subject to selection bias. If users are required to provide information to access content, they may prioritize speed over accuracy, degrading the quality of information.

Systems that foster information exchange to facilitate participation and truthfulness by using a "Netflix model" are one solution. Netflix shares recommendations for video content with its users and tethers those recommendations to what users have liked in the past. This procedure incentivizes users to share information with the platform to improve the quality of its future recommendations. This information is then used to benefit other users of the service by improving the quality of Netflix's recommendations to them. A comparable model could potentially work for agriculture. Farmers could be convinced to supply information on what has recently worked for them, because doing so would improve the advice the mobile-advisory service provides them in the future. Such a system would incentivize farmers to share their experiences, because sharing would enable them to receive better-tailored recommendations. The resulting data could also be used to improve recommendations for other, similar farmers.

Financing and governance of digital agriculture systems

Digital agricultural extension systems currently reach only a small proportion of farmers (*70*). Here, we discuss barriers to commercial scaling, as well as problems with public scaling and emerging evidence on ways to address them.

Barriers to scaling of subscription models

Many of the efforts to establish digital extension systems, such as iCow Global in Kenya or RML Agtech in India, have sought to finance themselves by selling subscriptions to farmers, but these types of efforts have reached only a small fraction of the potential market (*70*). Economic theory suggests that three features of markets for agricultural information—nonrivalry, nonexcludability, and asymmetric information—make it difficult for pure subscription models to reach as many farmers as would be efficient from a social point of view.

Nonrivalry

Information differs from most other goods (*71*, *72*). Creation of information involves fixed costs—for example, collecting data from soil tests and weather stations or designing, testing, and refining comprehensible and actionable messages for farmers. However, unlike most other goods, such as agricultural products, information is a nonrival commodity: Once it has been created, it can be used by additional people at a minimal marginal distribution cost, with no cost to others.

From a social point of view, it is efficient for all who value the information at more than the distribution cost to have access to it. However, a firm using a pure subscription model would need to charge a higher fee than the price of distribution to cover the fixed cost of information creation. As a result, some farmers for whom it would be efficient to obtain information would be excluded (Fig. 4). For the particular curve drawn, the majority of farmers would value the information at more than the cost of distribution, but only about one-third would be willing to pay the profit-maximizing price of a commercial firm using a pure subscription model.

In addition, under nonrivalry, a potential provider operating via a subscription model may not have the commercial incentives to create the service, even if it is socially efficient to do so. It is socially efficient to invest if the total area between the farmer valuation curve and the cost of distributing information—profits plus farmer surplus and deadweight loss—exceeds the cost of information creation. However, a private firm will invest only if the profits from selling information are sufficient to cover the cost of information creation. Nonrivalry leads to a gap between the conditions under which it is socially efficient to invest in the creation of the service and the conditions under which it will be privately profitable to do so.

More sophisticated forms of subscription models may ameliorate these distortions. To the extent that firms can charge different prices for information on the basis of farmers' willingness to pay, these firms can serve more farmers and increase their profits. "Freemium" models are a step in this direction because they give consumers a chance to learn about the quality of advice before they pay for it.

Nonrivalry does not imply that no knowledge-creation investments will be commercially viable. Indeed, a considerable share of all research and development investment is made by the private sector. If the only market failure associated with agricultural information markets was nonrivalry, then a subscription model might become viable once technological progress and the spread of smartphones and data plans sufficiently drove down the costs of information production and distribution. However, markets for agricultural information are subject to two additional distortions that further reduce farmers' willingness to pay for information.

Nonexcludability

Agricultural information is also nonexcludable or only partially excludable—i.e., once an individual has access to the information, this person can easily share it with others. In their study of digital agricultural extension in India, Cole and Fernando (*46*) found significant knowledge spillovers to farmers who had not received the services in the trial. A rich literature documents the flow of agricultural information in rural communities (*73*–*75*). Sharing of information not only directly reduces the number of potential customers for digital agricultural extension services but may also reduce willingness to pay among those who do purchase, which could affect the financial viability of subscription-based services.

In a study of willingness to pay for local soil information in western Kenya, individual farmers were not willing to pay the full cost of local soil test results (*76*). However, the aggregate valuation of all farmers for a given test in an area exceeded the cost of testing, potentially making investment in this information worthwhile from a social standpoint. Farmers' willingness to pay for information was also lower in a setting where they could ask others for the information, which suggests that the option of resale or free riding depressed any willingness to pay.

Asymmetric information

Buyers do not necessarily know the value of the information sold to them, and they may not trust sellers' claims about its value (*77*). Because agricultural production is highly variable and the profitability of recommended agricultural practices may differ from year to year, it may be difficult for farmers to assess the quality of advice, even after they purchase it.

Weak regulation makes it difficult to trust those selling information. Fraudulent operators can set up firms and offer useless information. Even firms with legitimate information would have incentives to inflate the benefits of their information. Farmers may thus discount any claims and reduce their willingness to pay for information. Markets for information can unravel entirely, preventing any transactions. Sellers address this issue by investing in a reputation for trustworthiness, but this involves some costs, and farmers may still retain doubts.

Beyond these distortions specific to agricultural information markets, other factors make selling any investment product in these markets difficult. Many developing-country farmers have no readily available cash and may not be able to borrow money either. In addition, a variety of behavioral factors, ranging from present bias to loss aversion, may inhibit investment (*27*). Customer acquisition costs and transaction costs in payments are also likely obstacles to successful scaling with subscription models.

Together, these factors erode farmers' willingness to pay for information and thus limit the financial viability of digital agricultural extension efforts. Cole and Fernando (*46*) estimate that their IVR service in India increased farmers' incomes by more than the costs of the service, but despite a high rate of farmer engagement, the average price a farmer was willing to pay for a 9-month subscription was only \$2, whereas the cost of provision was \$7.

Other commercial financing models

Beyond pure subscription models, other commercial models may partially address some of the market failures.

Contract farming

Some agricultural products, such as sugarcane or dairy, require local processing, often featuring a dominant local buyer. If the buyer profits sufficiently from having a greater input supply, this person may be willing to pay to provide digital agricultural extension services for all farmers in the area. Because the dominant buyer would want all farmers in the area to increase production, this would help address the problems of nonrivalry and nonexcludability. Additionally, a buyer with professional staff may be less subject to asymmetric information problems. The buyer may personally operate a digital agricultural extension service or purchase these services in bulk from another provider, thus reducing customer acquisition costs relative to the cost of selling to individual farmers.

This approach may be particularly effective when the buyer cares not only about the extra profits from greater input supply, but also about farmers. Dairy farmers, for example, often organize themselves into cooperatives that jointly buy milk-processing equipment. In some cases, lenders also provide digital agricultural advice.

Advertising and selling inputs

Digital agricultural extension providers could also try to finance themselves by selling advertising, selling own-brand inputs, or entering strategic alliances with agricultural input providers. Incentives such as commissions can lead to biased advice (*78*); nevertheless, some firms succeed in developing a reputation for providing objective advice. For example, Farmers Business Network in the United States has grown rapidly with a financial model based on selling own-brand agricultural inputs, as well as providing information.

As smartphones and data plans become more common and it becomes possible to transmit more types of information at low cost, advertising and input sales may generate enough revenue to finance some provision of agricultural information, but markets are still unlikely to deliver socially optimal outcomes. Information will probably be undersupplied on agricultural techniques that do not involve input purchases or that involve only purchases of inputs that have become commodified and hence have low markups. False or misleading information may be supplied on the merits of different brands or the suitability of techniques that involve input purchase. Although regulation could potentially address such issues, designing and implementing appropriate regulation is likely to be difficult.

Public financing and government provision

The above examples of market failures provide a rationale for the public sector to fully or partially finance provision of digital agricultural extension. A public-sector entity could either operate a digital agricultural extension service itself, as the government of Ethiopia currently does, or contract with or provide financial support for private providers, as donors in international development are currently doing. Governments could also use their position as regulators to encourage telecommunication firms to provide such services or to make capacity available to other digital agricultural extension providers.

Scaling through governments entails typically lower customer acquisition costs than faced by individual companies, because governments can leverage their relationships with telecommunications companies, the existing agricultural extension apparatus, and regulatory powers to draw farmers to their platforms. However, just as market solutions are subject to market failures, government solutions are subject to government failures. Governments are not known for nimble product development or user-friendly technology interfaces, and they lack the immediate customer feedback mechanism the market provides. Government agencies often provide agricultural information that might be too technical or detailed for communicating with the average farmer. For example, several Indian state governments distribute personalized soil health cards, based on local soil tests, to farmers. These cards are difficult for farmers to understand, and many farmers report never receiving them (*15*). Those who do receive the report cards often distrust the content (*79*). Simplifying the design, making the cards less technical, and complementing them with information delivered by mobile phones increased baseline comprehension from 8% to at least 40% (*15*). Similarly, a government-sponsored IVR helpline in Africa required farmers to answer a series of registration questions before they could access content, preventing many from reaching the agricultural content. Merely postponing user registration until after the farmers received some useful information increased the share of farmers getting to the content by approximately one-fifth, from 52 to 63% (*80*).

In these cases, governments responded to evidence by adjusting their programs, redesigning the soil health cards, and postponing registration requirements, raising the possibility that the systematic incorporation of ongoing surveys and A/B trials into government programs may serve as a partial substitute for the lack of market feedback.

However, governments, like private businesses, may distort information provision to farmers. For example, governments may want to increase production of certain commodities to achieve export goals, but they may not sufficiently value the time and effort required for farmers to adopt the corresponding agricultural practices. If government systems grow, input sellers may start lobbying or bribing government officials to recommend their brands as opposed to others.

Regulation

Digital agricultural extension raises regulatory questions that require further research. Information providers with financial interests in selling certain products might send misleading messages. One approach to tackling this challenge would be to mandate certain disclosures of financial conflicts. However, evidence from the regulation of financial and medical products industries suggests that such mandates are not sufficient (*81*). Telecommunications authorities typically have rules limiting phone spam and will have to decide whether specific emergencies, such as severe pest outbreaks, warrant waiving rules against sending unsolicited information. As smartphones and data plans spread, it will become cheaper to distribute content to farmers, so nonexcludability of information will be less of a barrier to information provision. But it is likely to become more difficult to control the provision of misleading information, and hence asymmetric information may become more of a problem.

Customization could have great potential benefits, but it also raises questions about how to protect users' privacy. Governments must decide whether and under what circumstances to share contact information for agricultural extension agents or farmers.

Regulatory issues arise even for messages sent by government agencies. Messages from an agricultural ministry, for example, could crowd out equally important health messages. Messages that misleadingly imply that socially desirable behavior (such as environmentally favorable agricultural practices) has individual benefits could reduce trust in all messages from the government. Too many messages could annoy people and make them feel uncomfortable (*82*).

Outlook

The available evidence suggests that the benefits of providing digital extension far exceed the costs but that subscription-based models will not reach optimal scale. This disparity creates a potential role for public financing, which LMIC governments and aid donors are increasingly supporting.

Delivering on the full promise of digital agriculture, including customization of information provision, will require sustained cycles of iteration and testing. The development of lessons that are viable and useful in multiple contexts will be essential to avoid reinventing the wheel for each application. Because these lessons may constitute a global public good, multilateral institutions and global donors may wish to financially support digital information provision efforts by governments or private actors in exchange for undertaking experimentation and making the results widely available. Equally, many of the emerging lessons on provision of information to farmers could also apply in other sectors, such as education or health.

REFERENCES AND NOTES

1. World Bank, "World Development Report 2016: Digital Dividends" (World Bank, 2016). doi: 10.1596/978-1-4648-0671-1
2. J. C. Aker, J. E. Blumenstock, "The economic impacts of new technologies in Africa" in *The Oxford Handbook of Africa and Economics: Volume 2: Policies and Practices*, C. Monga, J. Y. Lin, Eds. (Oxford Univ. Press, 2015), pp. 354–371.
3. J. C. Aker, I. M. Mbiti, Mobile Phones and Economic Development in Africa. *J. Econ. Perspect.* **24**, 207–232 (2010). doi: 10.1257/jep.24.3.207
4. J. C. Aker, "Using digital technology for public service provision in developing countries" in *Digital Revolutions in Public Finance*, S. Gupta, M. Keen, A. Shah, G. Verdier, Eds. (International Monetary Fund, 2017), pp. 201–224.

5. T. Suri, W. Jack, The long-run poverty and gender impacts of mobile money. *Science* **354**, 1288–1292 (2016). doi: 10.1126/science.aah5309; pmid: 27940873
6. J. H. Pierskalla, F. M. Hollenbach, Technology and Collective Action: The Effect of Cell Phone Coverage on Political Violence in Africa. *Am. Polit. Sci. Rev.* **107**, 207–224 (2013). doi: 10.1017/S0003055413000075
7. B. Qin, D. Strömberg, Y. Wu, Why Does China Allow Freer Social Media? Protests versus Surveillance and Propaganda. *J. Econ. Perspect.* **31**, 117–140 (2017). doi: 10.1257/jep.31.1.117
8. J. James, Digital Divide Complacency: Misconceptions and Dangers. *Inf. Soc.* **24**, 54–61 (2008). doi: 10.1080/01972240701774790
9. J. Blumenstock, N. Eagle, "Mobile divides: Gender, socioeconomic status, and mobile phone use in Rwanda" in *Proceedings of the 4th ACM/IEEE International Conference on Information and Communication Technologies and Development - ICTD '10* (Association for Computing Machinery, 2010), article no. 6; .doi: 10.1145/2369220.2369225
10. Food and Agriculture Organization of the United Nations (FAO), "The economic lives of smallholder farmers: An analysis based on household data from nine countries" (FAO, 2015); www.fao.org/3/a-i5251e.pdf.
11. Z. Cui *et al*., Pursuing sustainable productivity with millions of smallholder farmers. *Nature* **555**, 363–366 (2018). doi: 10.1038/nature25785; pmid: 29513654
12. B. K. Jack, "Market inefficiencies and the adoption of agricultural technologies in developing countries," [White paper, Agricultural Technology Adoption Initiative, JPAL (MIT)/CEGA (Berkeley), 2011]; https://escholarship.org/content/qt6m25r19c/qt6m25r19c.pdf.
13. J. Anderson, G. Feder, in *Agricultural Development: Farmers, Farm Production and Farm Markets,* vol. 3 of *Handbook of Agricultural Economics*, R. Evenson, P. Pingali, Eds. (Elsevier, 2007), pp. 2343–2378.
14. K. Davis, B. Swanson, D. Amudavi, D. A. Mekonnen, A. Flohrs, J. Riese, C. Lamb, E. Zerfu, "In-depth assessment of the public agricultural extension system of Ethiopia and recommendations for improvement" [International Food Policy Research Institute (IFPRI) Discussion Paper, IFPRI, 2010]; www.ifpri.org/publication/depth-assessment-public-agricultural-extension-system-ethiopia-and-recommendations.
15. S. Cole, G. Sharma, "The Promise and Challenges in Implementing ICT for Agriculture," Working paper (2017); https://precisionag.org/uploads/cole-sharma-july1-2017.pdf.
16. M. Gautam, "Agricultural extension: The Kenya experience: An impact evaluation" (World Bank Publications, 2000).
17. O. Bandiera, R. Burgess, E. Deserranno, R. Morel, I. Rasul, M. Sulaiman, "Social Ties and the Delivery of Development Programs," Working paper (2018); https://drive.google.com/file/d/1uESM-AfGaiY-7eZ7Zq1WBzyP1IKE4fuS/view.
18. J. R. Alwang, P. B. Siegel, "Rural poverty in Zambia: An analysis of causes and policy recommendations" (World Bank, 1994).
19. B. Cunguara, K. Moder, Is Agricultural Extension Helping the Poor? Evidence from Rural Mozambique. *J. Afr. Econ.* **20**, 562–595 (2011). doi: 10.1093/jae/ejr015
20. F. Kondylis, V. Mueller, G. Sheriff, S. Zhu, Do Female Instructors Reduce Gender Bias in Diffusion of Sustainable Land Management Techniques? Experimental Evidence From Mozambique. *World Dev.* **78**, 436–449 (2016). doi: 10.1016/j.worlddev.2015.10.036
21. K. A. Saito, H. Mekonnen, D. Spurling, "Raising the Productivity of Women Farmers in Sub-Saharan Africa" (Discussion paper, World Bank, 1994); .doi: 10.1596/0-8213-2749-6
22. R. A. Viscarra Rossel *et al*., A global spectral library to characterize the world's soil. *Earth Sci. Rev.* **155**, 198–230 (2016). doi: 10.1016/j.earscirev.2016.01.012
23. D. Arrouays, P. Lagacherie, A. E. Hartemink, Digital soil mapping across the globe. *Geoderma Reg.* **9**, 1–4 (2017). doi: 10.1016/j.geodrs.2017.03.002
24. P. A. Sanchez *et al*., Digital soil map of the world. *Science* **325**, 680–681 (2009). doi: 10.1126/science.1175084; pmid: 19661405
25. M. Rosenzweig, C. R. Udry, "Forecasting Profitability," Working paper 19334 [National Bureau of Economic Research (NBER) Working Paper Series, 2013]; .doi: 10.3386/w19334
26. R. B. Alley, K. A. Emanuel, F. Zhang, Advances in weather prediction. *Science* **363**, 342–344 (2019). doi: 10.1126/science.aav7274; pmid: 30679358
27. M. Kremer, G. Rao, F. Schilbach, "Behavioral development economics" in *Handbook of Behavioral Economics - Foundations and Applications 2*, B. D. Bernheim, S. DellaVigna, D. Laibson, Eds. (North Holland, 2019), pp. 345–458.
28. M. Burke, D. B. Lobell, Satellite-based assessment of yield variation and its determinants in smallholder African systems. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 2189–2194 (2017). doi: 10.1073/pnas.1616919114; pmid: 28202728
29. D. Donaldson, A. Storeygard, The View from Above: Applications of Satellite Data in Economics. *J. Econ. Perspect.* **30**, 171–198 (2016). doi: 10.1257/jep.30.4.171
30. K. Vasilaky, K. Toyama, T. Baul, M. Mangal, U. Bhattacharya, "Learning Digitally: Evaluating the Impact of Farmer Training via Mediated Videos" presented at the Northeast Universities Development Consortium Conference, Providence, RI, 7 and 8 November 2015; https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=NEUDC2015&paper_id=519.
31. M. Ridley, G. Rao, P. Vikram, F. Schilbach, "Poverty and Mental Illness: Causal Evidence" (2019); https://economics.mit.edu/files/18694.
32. S. Alan, T. Boneva, S. Ertac, Ever Failed, Try Again, Succeed Better: Results from a Randomized Educational Intervention on Grit. *Q. J. Econ.* **134**, 1121–1162 (2019). doi: 10.1093/qje/qjz006
33. E. La Ferrara, Aspirations, Social Norms, and Development. *J. Eur. Econ. Assoc.* 10.1093/jeea/jvz057 (2019). doi: 10.1093/jeea/jvz057
34. T. Bernard, S. Dercon, K. Orkin, A. S. Taffesse, "The future in mind: short and long-run impact of an aspirations intervention in rural Ethiopia," Working paper (Univ. of Oxford, 2018); http://ibread.org/bread/system/files/bread_wpapers/429.pdf.
35. G. Murthy, M. Fernandez-Vidal, X. Faz, R. Barreto, "Fintechs and Financial Inclusion: Looking past the hype and exploring their potential" (Consultative Group to Assist the Poor, 2019); www.cgap.org/sites/default/files/publications/2019_05_Focus_Note_Fintech_and_Financial_Inclusion_1_0.pdf.
36. M. T. Damgaard, C. Gravert, The hidden costs of nudging: Experimental evidence from reminders in fundraising. *J. Public Econ.* **157**, 15–26 (2018). doi: 10.1016/j.jpubeco.2017.11.005
37. U. P. Union, "Addressing the World–An Address for Everyone" (White paper, Universal Postal Union, 2012); www.upu.int/fileadmin/documentsFiles/activities/addressingAssistance/whitePaperAddressingTheWorldEn.pdf.
38. A. Erlich, D. F. Jung, J. D. Long, C. McIntosh, The double-edged sword of mobilizing citizens via mobile phone in developing countries. *Dev. Eng.* **3**, 34–46 (2018). doi: 10.1016/j.deveng.2017.11.001
39. J. C. Aker, Dial "A" for agriculture: A review of information and communication technologies for agricultural extension in developing countries. *Agric. Econ.* **42**, 631–647 (2011). doi: 10.1111/j.1574-0862.2011.00545.x
40. E. Nakasone, M. Torero, B. Minten, The power of information: The ICT revolution in agricultural development. *Annu. Rev. Resour. Econ.* **6**, 533–550 (2014). doi: 10.1146/annurev-resource-100913-012714
41. J. C. Aker, I. Ghosh, J. Burrell, The promise (and pitfalls) of ICT for agriculture initiatives. *Agric. Econ.* **47**, 35–48 (2016). doi: 10.1111/agec.12301
42. H. Baumüller, The Little We Know: An Exploratory Literature Review on the Utility of Mobile Phone-Enabled Services for Smallholder Farmers. *J. Int. Dev.* **30**, 134–154 (2018). doi: 10.1002/jid.3314
43. U. Deichmann, A. Goyal, D. Mishra, Will digital technologies transform agriculture in developing countries? *Agric. Econ.* **47**, 21–33 (2016). doi: 10.1111/agec.12300
44. C. Larochelle, J. Alwang, E. Travis, V. H. Barrera, J. M. D. Andrade, Did You Really Get the Message? Using Text Reminders to Stimulate Adoption of Agricultural Technologies. *J. Dev. Stud.* **55**, 548–564 (2019). doi: 10.1080/00220388.2017.1393522
45. X. Fu, S. Akter, The Impact of Mobile Phone Technology on Agricultural Extension Services Delivery: Evidence from India. *J. Dev. Stud.* **52**, 1561–1576 (2016). doi: 10.1080/00220388.2016.1146700
46. S. A. Cole, A. N. Fernando, "'Mobile'izing Agricultural Advice: Technology Adoption, Diffusion and Sustainability," Working paper (2018); www.dropbox.com/s/0rewpp8oeost0o5/ao_final_v24_tables.pdf?dl=0.
47. R. Fabregas, M. Kremer, M. Lowes, R. On, G. Zane, "SMS-extension and Farmer Behavior: Lessons from Six RCTs in East Africa," Working paper (2019); www.dropbox.com/s/guiog3ief0hnwl7/textfarmers.pdf?dl=0.
48. L. Casaburi, M. Kremer, S. Mullainathan, R. Ramrattan, "Harnessing ICT to increase agricultural production: Evidence from Kenya," Working paper (2019); www.econ.uzh.ch/dam/jcr:873845ce-de4d-4366-ba9a-d60accda577d/SMS_paper_with_tables_20190923_merged.pdf.
49. B. Van Campenhout, W. Walukano, F. Nattembo, L. Nazziwa-Nviiri, J. Blom, "The Role of Information in Agricultural Technology Adoption: Experimental Evidence from Rice Farmers in Uganda" (IFPRI Discussion Paper, IFPRI, 2017); https://core.ac.uk/download/pdf/153429888.pdf.
50. B. Van Campenhout, D. J. Spielman, E. Lecoutere, "Information and Communication Technologies (ICTs) to Provide Agricultural Advice to Smallholder Farmers: Experimental Evidence from Uganda" (IFPRI Discussion Paper, IFPRI, 2018); www.ifpri.org/publication/information-and-communication-technologies-icts-provide-agricultural-advice-smallholder.
51. A. Arounaa, J. D. Michlerb, W. G. Yergoa, K. Saitoa, "One Size Does Not Fit All: Experimental Evidence on the Digital Delivery of Personalized Extension Advice in Nigeria" (2019); www.researchgate.net/publication/336927609_One_Size_Does_Not_Fit_All_Experimental_Evidence_on_the_Digital_Delivery_of_Personalized_Extension_Advice_in_Nigeria.
52. C. Udry, "Information, Market Access and Risk: Addressing Constraints to Agricultural Transformation in Northern Ghana" (2019); https://sites.northwestern.edu/christopherudry/files/2019/03/DIRTS-Final-report-1362c0g.pdf.
53. R. Gandhi, R. Veeraraghavan, K. Toyama, V. Ramprasad, "Digital Green: Participatory video for agricultural extension," in *2007 International Conference on Information and Communication Technologies and Development* (IEEE, 2007). doi: 10.1109/ictd.2007.4937388
54. E. Tjernström, T. J. Lybbert, R. Frattarola Hernández, J. S. Correa, "Learning by (virtually) doing: experimentation and belief updating in smallholder agriculture" (2019); www.lafollette.wisc.edu/sites/tjernstrom/Learning_by_virtually_doing.pdf.
55. R. Jensen, The Digital Provide: Information (Technology), Market Performance, and Welfare in the South Indian Fisheries Sector. *Q. J. Econ.* **122**, 879–924 (2007). doi: 10.1162/qjec.122.3.879
56. J. C. Aker, Information from Markets Near and Far: Mobile Phones and Agricultural Markets in Niger. *Am. Econ. J. Appl. Econ.* **2**, 46–59 (2010). doi: 10.1257/app.2.3.46
57. J. C. Aker, M. Fafchamps, Mobile Phone Coverage and Producer Markets: Evidence from West Africa. *World Bank Econ. Rev.* **29**, 262–292 (2015). doi: 10.1093/wber/lhu006
58. J. Svensson, D. Yanagizawa, Getting Prices Right: The Impact of the Market Information Service in Uganda. *J. Eur. Econ. Assoc.* **7**, 435–445 (2009). doi: 10.1162/JEEA.2009.7.2-3.435
59. P. Courtois, J. Subervie, Farmer Bargaining Power and Market Information Services. *Am. J. Agric. Econ.* **97**, 953–977 (2015). doi: 10.1093/ajae/aau051
60. E. Nakasone, "The Role of Price Information in Agricultural Markets: Experimental Evidence from Rural Peru," Working paper (2014); https://fc317c2d-a-62cb3a1a-s-sites.googlegroups.com/site/eduardonakasone/Nakasone%20-%20Price%20Info%20and%20Ag%20Markets%20-%20OCT2014.pdf?attachauth=ANoY7crbtOVyu8ZK0saI6LjZFX5YTjR1uGo1cHVxIjGqIIwCGBxMJ_IINbLwB9TYQn6vfZSW7oI2aX2JLozIxPvAWqbjvGZDtpdAtqLTQTQyWHFL4OMZ2294iGS4VN2afdYzi-rbC5gUKq8ADwq0aKtPVCX0iAMynd5Q3QK2oIjTngQPoyLOYuNdJrQtyFxJV3pnkb9kLrEE8X6_oO2JBZJiF2snZppL-Edb5LwSVErpxNJJa4DARTJXcQPIsm7suHAaddvPwWGSiX75x7mE–gG9osAIVdVGg%3D%3D&attredirects=0&d=1.
61. M. Fafchamps, B. Minten, Impact of SMS-Based Agricultural Information on Indian Farmers. *World Bank Econ. Rev.* **26**, 383–414 (2012). doi: 10.1093/wber/lhr056
62. A. Camacho, E. Conover, "The Impact of Receiving Price and Climate Information in the Agricultural Sector," Working paper no. IDB-WP-220 [Inter-American Development Bank (IDB) Working Paper Series, 2011]; doi: 10.2139/ssrn.1755057
63. S. Mitra, D. Mookherjee, M. Torero, S. Visaria, Asymmetric Information and Middleman Margins: An Experiment with Indian Potato Farmers. *Rev. Econ. Stat.* **100**, 1–13 (2018). doi: 10.1162/REST_a_00699
64. L. Casaburi, M. Kremer, R. Ramrattan, "Crony Capitalism, Collective Action, and ICT: Evidence from Kenyan Contract Farming," Working paper (2019); http://econ.uzh.ch/dam/jcr:e2ffc4e5-ab32-4405-bfa4-70b0e962aa81/hotline_paper_20191015_MERGED.pdf.
65. R. J. Sexton, Imperfect Competition in Agricultural Markets and the Role of Cooperatives: A Spatial Analysis. *Am. J. Agric. Econ.* **72**, 709–720 (1990). doi: 10.2307/1243041
66. T. Bold, K. C. Kaizzi, J. Svensson, D. Yanagizawa-Drott, Lemon Technologies and Adoption: Measurement, Theory and Evidence from Agricultural Markets in Uganda. *Q. J. Econ.* **132**, 1055–1100 (2017). doi: 10.1093/qje/qjx009

67. S. Cole, T. L. He, "Farmers Business Network: Putting Farmers First," Harvard Business School Case 217-025 (2018); www.hbs.edu/faculty/Pages/item.aspx?num=51649.
68. B. Dillon, Using mobile phones to collect panel data in developing countries. *J. Int. Dev.* **24**, 518–527 (2012). doi: 10.1002/jid.1771
69. M. Jones, F. Kondylis, Does feedback matter? Evidence from agricultural services. *J. Dev. Econ.* **131**, 28–41 (2018). doi: 10.1016/j.jdeveco.2017.10.013
70. M. Tsan, S. Totapally, M. Hailu, B. K. Addom, "The digitalization of African agriculture report 2018-2019: Executive summary" (CTA/Dalberg Advisers, 2019); https://cgspace.cgiar.org/bitstream/handle/10568/103198/Executive%20Summary%20V4.5%20ONLINE.pdf.
71. K. J. Arrow, "Economic welfare and the allocation of resources for invention" in *The Rate and Direction of Inventive Activity: Economic and Social Factors* (Princeton Univ. Press, 1962), pp. 609–626.
72. P. M. Romer, Increasing Returns and Long-Run Growth. *J. Polit. Econ.* **94**, 1002–1037 (1986). doi: 10.1086/261420
73. A. D. Foster, M. R. Rosenzweig, Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture. *J. Polit. Econ.* **103**, 1176–1209 (1995). doi: 10.1086/601447
74. T. G. Conley, C. R. Udry, Learning about a new technology: Pineapple in Ghana. *Am. Econ. Rev.* **100**, 35–69 (2010). doi: 10.1257/aer.100.1.35
75. L. Beaman, A. BenYishay, J. Magruder, A. M. Mobarak, "Can Network Theory-based Targeting Increase Technology Adoption?" Working paper 24912 (NBER Working Paper Series, 2018); .doi: 10.3386/w24912
76. R. Fabregas, M. Kremer, J. Robinson, F. Schilbach, "The Value of Local Agricultural Information: Evidence from Kenya," Working paper (2019); www.dropbox.com/s/bumw8uj5dyhnt9n/valueinformation.pdf?dl=0.
77. G. A. Akerlof, The Market for "Lemons": Quality Uncertainty and the Market Mechanism. *Q. J. Econ.* **84**, 488 (1970). doi: 10.2307/1879431
78. S. Anagol, S. Cole, S. Sarkar, Understanding the Advice of Commissions-Motivated Agents: Evidence from the Indian Life Insurance Market. *Rev. Econ. Stat.* **99**, 1–15 (2017). doi: 10.1162/REST_a_00625
79. R. Fishman, A. Kishore, Y. Rothler, P. S. Ward, S. Jha, R. K. P. Singh, "Can information help reduce imbalanced application of fertilizers in India?: Experimental evidence from Bihar" (IFPRI Discussion Paper, IFPRI, 2016); http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/130249/filename/130460.pdf.
80. Precision Agriculture for Development, "Mid-term evaluation of IVR/SMS project: Findings and recommendations" (Ethiopian Agricultural Transformation Agency, 2018); https://precisionag.org/uploads/January-ATA-PAD-Report-FINAL-FOR-VALIDATION-WORKSHOP-compressed.pdf.
81. G. Loewenstein, S. Sah, D. M. Cain, The unintended consequences of conflict of interest disclosure. *JAMA* **307**, 669–670 (2012). doi: 10.1001/jama.2012.154; pmid: 22337676
82. H. Allcott, J. B. Kessler, The Welfare Effects of Nudges: A Case Study of Energy Use Social Comparisons. *Am. Econ. J. Appl. Econ.* **11**, 236–276 (2019). doi: 10.1257/app.20170328

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SUPPLEMENTARY MATERIALS

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Supplementary Text
References (*83*–*86*)

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Science

Realizing the potential of digital development: The case of agricultural advice

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Mobile farming advice

Mobile phones are almost universally available, and the costs of information transmission are low. They are used by smallholder farmers in low-income countries, largely successfully, to optimize markets for their produce. Fabregas *et al.* review the potential for boosting mobile phone use with smartphones to deliver not only market information but also more sophisticated agricultural extension advice. GPS-linked smartphones could provide locally relevant weather and pest information and video-based farming advice. But how to support the financial requirements of such extension services is less obvious, given the unwieldiness of government agencies and the vested interests of commercial suppliers.

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