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Experimental Insights on the Constraints to Agricultural Technology Adoption

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Abstract: Policymakers interested in improving the productivity and profitability of smallholder farmers in Sub-Saharan Africa and South Asia need to understand what prevents farmers from adopting technologies and effectively accessing markets. We summarize recent experimental evidence on constraints to agricultural technology adoption among smallholder farmers in these regions. The evidence presented builds from a series of policy insight summaries produced by the Agricultural Technology Adoption Initiative (ATAI)[1]. The underlying studies have been selected (and in many cases funded) by ATAI because they provide evidence using randomized controlled trials (RCTs) to understand and improve the low take-up of agricultural technology in the developing world. These summaries have been structured intellectually by the economic constraint they seek to address, and we present here the four constraints that have seen the largest amount of experimental work in recent years: credit and savings; risk; information; and input and output markets. In the sections that follow, we briefly motivate the role of each specific constraint, provide a summary of the recent experimental evidence and key outstanding questions, and work to draw a series of conclusions relevant for agricultural policy and practice.


INTRODUCTION

Randomized evaluations of the agronomic productivity gains from new crops or agricultural techniques have been common in the agricultural field for many years. More recent is an approach to agriculture that aims to conduct 'effectiveness' trials, incorporating real-world issues of access and adoption among smallholder farmers, rather than the idealized 'efficacy' trials produced using experimental test plots. Tackling the impacts of agricultural interventions outside of the test plot introduces issues at the heart of economics, such as transaction costs, social interactions, marketing, finance, and contracting as we think carefully about the decision to adopt. Thinking of the smallholder farm as a small business, this decision should be driven by profitability.

The core contribution of RCTs is their ability to clearly trace causality between the constraints to agricultural technology adoption, adoption itself (e.g. of seeds, fertilizers, training, etc.) and final outcomes (e.g. individual yields, nutrition, and profitability). Randomized experimental evaluations allow researchers to isolate the causal impact of a program from other confounding factors—such as price, weather, or access to credit—which are simultaneously changing over time and across regions (See the figure below providing a basic overview of randomization as a tool to measure the causal effects of interventions)[2]. Carefully designed experiments allow us to identify whether specific constraints to adoption are binding, and measure the impacts of a technology when adopted in farmers' actual fields. These evaluations speak to the effectiveness of specific approaches to achieving agricultural technology adoption for improved smallholder productivity and welfare.[3]

Randomized evaluations provide a highly rigorous estimate of program impact

Before the program starts, eligible individuals are randomly assigned to two or more groups so that they are statistically identical before the program.
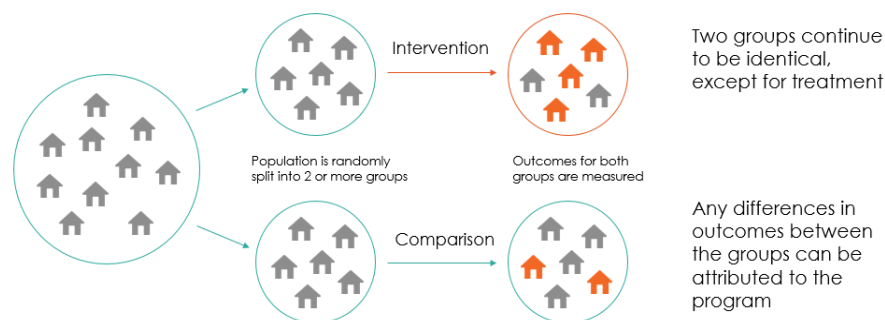
The Agricultural Technology Adoption Initiative (ATAI) was founded in 2009 to increase the quantity and quality of experimental evidence in developing-country agriculture[4]. ATAI aims to serve as a mechanism to generate, aggregate, and summarize research for policy outreach on the adoption of agricultural innovations by smallholders in Sub-Saharan Africa and South Asia. ATAI exclusively funds randomized controlled trials, and pilot work that lays the groundwork for future RCTs, and was organized intellectually around understanding how a set of specific constraints held back technology adoption. Because of this methodological focus, the resulting evidence is primarily on interventions targeted at the individual or household level, although we also report on

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[2] For more information on the appropriate design and use of randomized evaluations, we recommend J-PAL's Introduction to Evaluations found at https://www.povertyactionlab.org/research-resources/introduction-evaluations, and for a discussion of the contributions of randomized evaluations to development economics research and policy, see (Banerjee et al. 2016)

[3] Further discussion is presented in "Field Experiments in Developing Country Agriculture" (de Janvry, Sadoulet, Suri 2016)

[4] ATAI has funded a series of research grant competitions among our affiliates, made possible by generous support from the Bill & Melinda Gates Foundation, UK Aid from the British people, and an anonymous donor.

studies in areas such as input and output markets that attempt to drive outcomes at more aggregated levels. Even within this domain, we have a distribution of studies that is purposive, driven by the questions asked by our affiliated investigators, and by the technical feasibility of running randomized trials. We use the structure of the ATAI constraints to adoption to help summarize the experimental evidence, aggregating individual, internally valid studies around these common themes. This produces an evidence base that is far from comprehensive in terms of the important issues in agricultural development, but is broader than would have been produced by a more tightly structured replication-focused research initiative and does provide a relatively clear guide to what makes specific interventions attractive in terms of evidence-based funding.
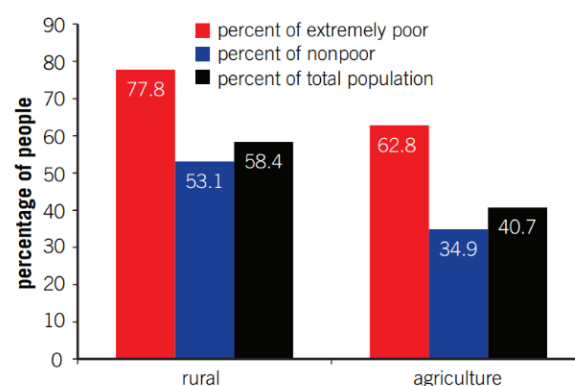
THE 'PUZZLE' OF AGRICULTURAL TECHNOLOGY ADOPTION

Throughout the world, 63% of those living under $1.25 per day are working in agriculture (see "Figure 7" at right extracted from Olinto et al. 2013). Improving agricultural production and profits is an important component of poverty alleviation. Ligon and Sadoulet (2017) show the importance of economic growth in the agriculture sector for the livelihoods of the poorest households: a one percent growth in GDP that originates from agriculture correlates with a 5.6 percentage point increase in expenditures among the poorest decile of the population, a 4.45 percentage point increase for the bottom 30%, while "growth from non-agriculture sectors does not appear to have a significant effect on expenditure growth for the poorest 50%."

Figure 7. Most of the Poor Live in Rural Areas and Work in Agriculture

Source: World Bank staff estimates based on I2D2.

The Green Revolution of the 1960s saw the spread of agricultural technologies to less industrialized nations, and large agricultural productivity gains particularly in East Asia. Yet technological innovations have not similarly spread to transform agricultural productivity in Sub-Saharan Africa and parts of South Asia as evident in the lagging adoption of modern varieties (see Tables 8.1, 8.2 and Figure 8.3 below from the IFAD Rural Development Report 2016) and a persistent yield gap between regions.

TABLE 8.1 **Area planted to modern varieties, 1960-2000 (% of total area harvested)**

	Year	Sub-Saharan Africa	East and South-East Asia and Pacific	South Asia	Middle East and North Africa	Latin America and the Caribbean
Rice	1960	0.0	0.0	0.0	0.0	0.0
	1970	0.0	9.7	10.2	0.0	4.7
	1980	3.1	40.9	36.3	2.2	16.2
	1990	12.3	63.5	52.6	4.3	27.8
	2000	31.0	80.5	71.0	10.4	32.3
Wheat	1960	0.0	0.0	0.0	0.0	0.0
	1970	0.4	0.0	39.6	7.6	11.4
	1980	4.1	27.5	78.2	33.8	61.3
	1990	6.3	58.7	87.3	43.8	79.3
	2000	47.4	89.1	94.5	69.1	93.2
Maize	1960	0.0	0.0	0.0	n.a.	0.0
	1970	0.0	16.2	17.1	n.a.	1.6
	1980	0.4	61.7	34.4	n.a.	11.2
	1990	7.5	73.0	47.1	n.a.	27.0
	2000	16.8	89.6	53.5	n.a.	56.5

Source: Gollin et al. 2005, p. 1313, based on data shared by Robert E. Evenson

Many African countries have rising private sectors developing agricultural technologies, and research and implementation groups including the CGIAR centers and AGRA continue to develop improved inputs and interventions designed to improve the resilience, profits, and nutrition of African smallholders in particular. Yet these innovations do not appear to have translated into meaningful improvements in yields at the macro-level. FAOSTAT data shows a large gap between low per hectare cereal yields in Africa and South Asia which are on average roughly one third of the per hectare yields in East Asia and OECD countries.
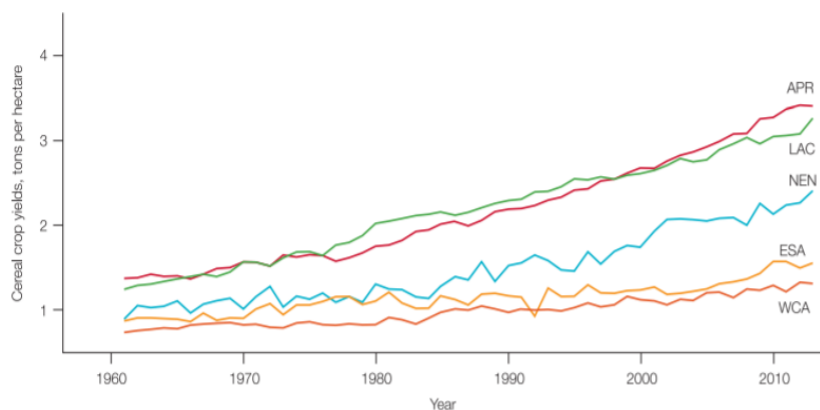
Sub-Saharan Africa is particularly lagging behind. In South Asia, land use for cereal production has increased 20% while yields have tripled. In Sub-Saharan Africa, land use for cereal production has more than doubled, while yields have increased by just 80% (World Bank, 2017 - Land under cereal production index). The macro picture of fertilizer use over time similarly looks unchanged, with low and stagnant use of fertilizers in mainly rainfed areas like Sub-Saharan Africa. Fertilizer consumption remains extremely low in Sub-Saharan Africa compared to other regions. Roughly 16 kilos of fertilizer are used per hectare in Sub-Saharan Africa, and among all developing countries the average is 26.75 kg/hectare. This figure is much higher in other regions: 344 kg/hectare in East Asia/Pacific, and 159 kg/hectare in South Asia.

TABLE 8.2 Adoption of modern crop varieties (MV) in Africa and the contribution of CGIAR, circa 2010

	Total area (million ha)	MV area (million ha)	% MV of total area (%)	MV area CGIAR related (%)
Maize	24.67	13.03	53	55
Sorghum	17.97	4.93	27	78
Cassava	11.04	4.38	40	83
Rice	6.79	2.58	38	51
Pearl millet	14.09	2.55	18	87
Groundnut	6.36	1.85	29	86
Yam	4.67	1.41	30	50
Soybean	1.19	1.04	87	63
Wheat	1.45	0.85	59	65
Bean	2.50	0.72	29	81
Other crops[a]	16.99	4.63	27	61
Total	107.72	37.97	35	66

[a] Includes pigeonpea, potato, barley, chickpea, fababean, lentil, sweet potato and field pea, all with less than 0.5 million hectares of MV adoption.
Source: Walker et al. 2015, chapter 19, with selections made by Derek Byerlee for this tabulation.

FIGURE 8.3 Trends in cereal crop yields, by region

Note: APR = Asia and the Pacific, ESA = East and Southern Africa, WCA = West and Central Africa, LAC = Latin America and the Caribbean, NEN = Near East, North Africa, Europe and Central Asia.
Source: IFAD, based on FAOSTAT.

Fertilizer use in kg per hectare of arable land
Fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate). Animal and plant manures are not included.
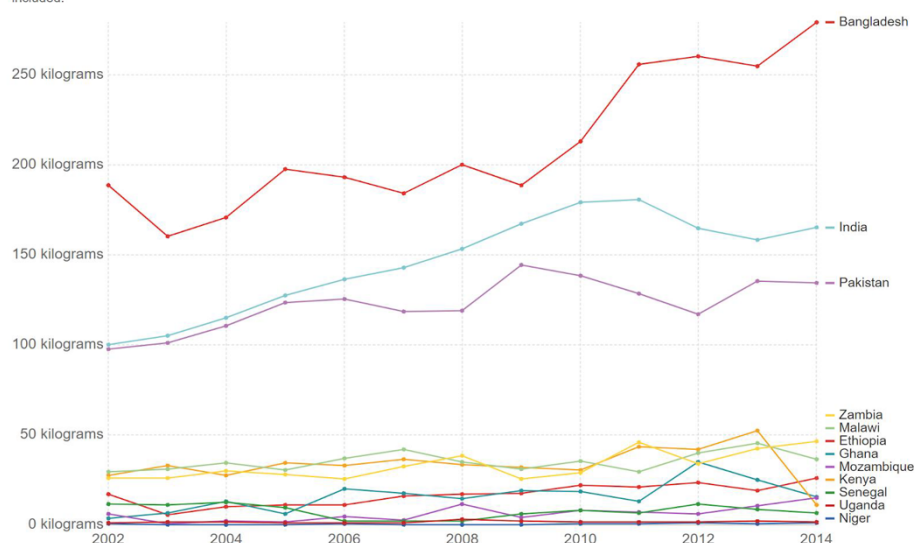
Source: World Bank – WDI: Fertilizer consumption (kilograms per hectare of arable land)   OurWorldInData.org/fertilizer-and-pesticides/ • CC BY-SA

This clearly demonstrates that the status quo of agricultural production, particularly in Sub-Saharan Africa, remains far below the technological frontier, suggesting missed potential in terms of yields, income, and welfare improvements to food security and nutrition. The specific reasons behind lagging adoption of productivity-enhancing technological innovations and persistent yield gaps in rainfed Sub-Saharan Africa and South Asia relative to the rest of the world have been a puzzle in need of policy solutions.

Field experiments help us move beyond test plots to explain the continuing puzzle of low technology adoption by smallholder farmers in rainfed areas where agriculture is performing well below the technological frontier. Focusing at the microeconomic level of this challenge, we focus on technology adoption as an outcome that inherently requires smallholder farmers to change their practices. Behavior changes can include, for example, the adoption of resilient and high-yielding crop varieties or a shift to high-value crops, the purchase and application of complementary inputs such as fertilizers, and the adjustment of farm labor allocated toward specific agronomic practices.

Many smallholder farmers face barriers to adopting effective agricultural technologies. These constraints to adoption may be driven by standard economic factors (such as prices or availability), or may be behavioral (driven by dimensions such as time inconsistency or ambiguity aversion).

Standard economic explanations consider smallholder farmers as economic agents, building from the conception that "in a well-functioning economy where markets perfectly capture all costs and benefits, and individuals are fully informed and unconstrained, farmers will adopt a technology if they make a profit from adopting it" (Jack 2013). This is an important distinction from a world where farmers focus their efforts to maximize their productivity, for example, their crop yields, given increased yields do not necessarily lead to improved welfare. Profitability can be limited by input costs, credit constraints, and market access. Information and labor constraints are also relevant -- how well do farmers understand the properties of new technologies, in the absence of opportunities to experiment? What are the additional labor requirements for the use of these new technologies, and how do farmers value their time in input decisions? Jack (2013) reviews in detail other dimensions that mediate whether certain technologies "meet the expected profitability condition" for specific farmers. This varies temporally (prices, weather realizations, and other shocks) and spatially (soil chemistry, microclimates, and distances from urban centers). This also varies between and within households, particularly when complementary asset or capital investments are needed, or new technologies challenge individual tastes and preferences.

Even where markets are functioning well, accessible and profitable technologies may not be adopted for behavioral reasons, such as risk or uncertainty aversion or procrastination, which challenge decision-making even in the best of circumstances. Smallholders' decision-making is highly complex and conducted in risky and low resource environments. Farmers make interconnected choices over long timeframes that are characterized by risks and uncertainty. One of many choices is among a range of potential inputs to production (crop choice, seed, labor, fertilizer, etc.), in contexts with highly variable land, wide ranging and seasonal climatic variation that is growing increasingly extreme given climate change, and unpredictable shocks to their livelihood. New technologies may change the risk or payoff profiles of farming in ways that require us to incorporate other social science insights, for example expected utility theory and behavioral economics, in order to understand perceived benefits at the farmer level.

Motivated by addressing the constraints hindering the adoption of new agricultural technologies, ATAI has worked to fund and structure the experimental evidence base across seven primary market inefficiencies that

constrain adoption. These are (1) credit[5], (2) risk, (3) information, (4) input and output markets, (5) labor and (6) land market inefficiencies, as well as (7) externalities (see Jack, 2013 for a more detailed summary). These may operate through supply or demand channels, for example by limiting the availability of technologies, information, or financing, and/or dampening demand by lowering expected profits. Lessons from psychology and behavioral economics are considered where they are particularly relevant. Jack (2013) motivates the focus on constraints to adoption, rather than specific technologies, as a framework that helps identify effective strategies to address common inefficiencies and constraints in order to encourage the adoption and use of more than one technology.

ATAI uses this conceptual framework of seven constraints to drive its research competitions. Randomized evaluations are selected for ATAI funding based not only on methodological rigor, logistical viability, and innovation, but also on their potential for both a significant contribution to public knowledge, and practical influence and scalability in related contexts. Field experiments require, by their very nature, durable partnerships with real-world implementation groups that are working directly with smallholder farmers in order to randomize interventions and deliver credible results. Partner organizations may work as agro-dealers, contract farming groups, extension agents, financial service providers, technology developers, or otherwise. ATAI views more favorably studies that evaluate questions of key importance to large-scale program and policy partners, particularly those that are difficult to address without causal evidence, and those that have received less research attention to date.

To meet these criteria, technologies under investigation are those where there is credible field data signaling that adoption would prove neither distasteful nor ineffective in target farmers' contexts, and that the take-up and use of a technology is likely to prove utility-enhancing, profitable, and welfare-increasing for smallholder farmers and others along agricultural value chains. For such promising under-adopted technologies, ATAI funds social science field experiments to provide evidence on the strategies that work in helping farmers adopt, and ultimately benefit from, these technologies.

In the sections that follow, we summarize particular components of the evidence base given the accumulation of ATAI-generated experimental evidence in four areas: (1) credit and savings, (2) risk, (3) information, and (4) input and output market inefficiencies. This does not imply that the latter three (of the seven total) constraints to adoption, i.e. externalities and land and labor markets, are excluded from this chapter because they do not bind or do not deserve further investigation. These topics are not covered here simply because there is less rigorous micro-evidence given the difficulty of examining them through the lens of RCTs[6]. This is not intended to be an exhaustive review. ATAI-funded studies are often presented in greater detail given our familiarity with their contributions. Each section begins by motivating the specific constraint to technology adoption, pulling from a range of rigorous non-experimental work and some theoretical work to characterize the constraint facing farmers. We then summarize findings from recent randomized evaluations in an effort to distill policy-relevant insights.

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[5] When presenting the constraints to agricultural technology adoption framework, "credit" is sometimes used as shorthand for "credit market inefficiencies." Interventions targeting this constraint can be credit, savings, or other services that help provide access to liquidity.

[6] Fortunately, these topics are taken up in Jack 2013, using other methodologies to discuss the role of factor markets for productivity growth in agriculture. There are limited examples of randomized evaluations of securing land tenure, although preliminary results are available in Uganda, Benin, and Rwanda from Goldstein et al. at the World Bank Gender Innovation Lab.

CREDIT AND SAVINGS

MOTIVATION

Agricultural income streams are characterized by large cash inflows once or twice a year that do not align well with specific times when farmers need access to capital to either make agricultural investments or, for example, pay school fees. If there is limited access to credit in an area, farmers may not have cash on hand to make agricultural productivity investments unless they are able to save, or can afford the potentially high interest rates of informal lending. However, saving can be difficult for farmers given their limited resources, a variety of demands on their money, and the seasonal cycle of production and prices of their agricultural production. Credit and saving products could help farmers make investments in inputs and other technologies by making cash available when needed. Yet many developing countries, and particularly rural areas, have limited access to formal financial services that could provide this liquidity. Credit constraints have been reflected in farmers self-reports (Croppenstedt et al. 2003; Burke, Falcao Berquist, and Miguel 2017), and are associated with less use of productive inputs like high-yielding varieties (Njagi et al. 2017).

On the supply side, formal financial service providers are often unwilling or unable to serve smallholders. Few products suitable to agricultural livelihoods are available, and despite the wide proliferation of microfinance institutions (MFIs), most are limited to nonagricultural activities given there are substantial challenges inherent in long-cycle agricultural lending (Morduch 1999; Armendariz de Aghion and Morduch 2005). Lenders in these contexts charge high interest rates to help offset their assessment of the risk that loans will not be repaid. These higher interest rates can, perversely, have the effect of attracting only borrowers with no intention of repaying (adverse selection), thus driving interest rates even higher, as lenders seek to offset increased risk (Stiglitz and Weiss 1981), further reducing access to credit for the small-scale farmer (Banerjee and Newman 1994; Bardhan and Udry 1999; Conning and Udry 2007). Group-liability microfinance models, though popular in urban markets to reach low-income borrowers through social guarantees, may be ill-suited to serve smallholders in contexts where dominant risks driving default like weather and price shocks are common among members in the localized group. Group members will be unable to insure other members who cannot pay off a loan if, for example, everyone's harvest is devastated by the same local flood or pest.

On the demand side, demand from farmers for formal credit products is low. Even where formal financial products are available, farmers may opt to borrow money from within their social networks, or informal lenders. Preliminary findings from the rollout of Kshetriya Grameen Financial Services (KGFS), a microfinance portfolio in rural Tamil Nadu, show that 72% of farmers' loans at the beginning of the season are from formal sources, but only 35% are from formal sources by the end of the season. Farmers seem to shift to informal borrowing given quick loan approvals and more flexible (though more costly) loan terms are available. This use of informal borrowing is particularly prevalent among marginalized farmers: 82% of the agricultural loans taken out by marginal farmers were from informal sources compared to 46% among medium-landholding farmers (EPoD IFMR LEAD Policy Brief 2016). Even where formal financial services are available, they are often highly disadvantageous to smallholder farmers. Farmers' credit needs are different from urban microcredit customers for which the common microcredit products are designed, with weekly repayments and group liability. Most loan offers and repayment schedules are poorly timed to fit seasonal production cycles and price fluctuations. Uncertainty or risk aversion can also make farmers hesitant to take on debt. Profits in farming are uncertain, and are often low without complementary investments. Options for collateral to back a loan are limited in these environments, and assets like land may be too fundamental to basic livelihood to risk in order to access a line of credit (Boucher 2008), or unacceptable to back a loan in insecure contracting environments. Accessing and using financial products can also be even more difficult for farmers without high levels of financial literacy.

These credit market inefficiencies result in limited access to liquid capital from formal financial services. There is policy appetite to leverage new technologies and approaches to expand formal credit and savings mechanisms to rural households, particularly given the proliferation of microcredit in urban markets. But even where microcredit has expanded widely among low-income urban clientele, evidence from randomized impact evaluations show limited ability for microcredit to transform the average entrepreneur's business productivity and revenues, instead providing value through increased flexibility in how households "make money, consume, and invest" (J-PAL and IPA Policy Bulletin 2015). In the smallholder context, we focus specifically on whether expanding access to formal credit on the margin of what is already available shows potential to unlock productive, profitable investments that improve rural livelihoods. Where expanding access to credit shows potential, studies investigate product designs aiming to increase credit access and their benefits specifically for smallholder farmers.

EXPERIMENTAL EVIDENCE SUMMARY:
IMPACTS OF FINANCIAL SERVICES AND LESSONS FOR PRODUCT DESIGN

1. **Increasing access to formal credit has typically had limited impacts on smallholder farmers' profitability:** Low take up of credit is one reason behind these limited impacts. A review of nine randomized evaluations that expanded access to credit on the margin of what's available informally for smallholders in these contexts showed that a majority of farmers did not use credit when it was offered to them. In studies in Mali (Beaman et al. 2015a), Malawi (Giné and Yang 2009), Morocco (Crépon et al. 2015), and Sierra Leone (Casaburi et al. 2014), only between 17 and 33 percent of eligible farmers took up the loans that they were offered[7]. This is not dissimilar to the takeup rates observed from randomized evaluations of more traditional, typically urban, group-liability microfinance: "In Ethiopia, India, Mexico, and Morocco, when MFIs offered loans to eligible borrowers, take-up ranged from 13 to 31 percent, which was much lower than partner MFIs originally forecasted" (J-PAL and IPA Policy Bulletin 2015). However, we can investigate the impacts of credit on those smallholders who do take up the new products. The following randomized evaluations found that while farmers who used newly available credit products invested in more productive technologies and practices such as crops grown, land cultivated, and inputs[8] used, in most cases this access to credit did not increase their profits (Beaman et al. 2015a). For example, households who took up loans in Morocco invested more in agriculture and animal husbandry (Crépon et al. 2015), while in Ethiopia, microcredit increased crop-related expenditures including seeds and fertilizer, and wages and rents for land and equipment (Tarozzi et al. 2013). However, neither detected any increase in profits. Key exceptions (Burke et al. 2017, Fink et al. 2014, and Maitra et al. 2017) will be described later in this section when discussing the evidence for improved credit product design.

2. **Targeted savings products can increase agricultural investment, but encouraging active use of these products can be a challenge:** Takeup rates in terms of either accepting assistance to open a savings account or agreeing to participate in communal savings groups ranged from 54-90% in four randomized trials in rural areas of Kenya (Dupas, Keats, and Robinson 2015), Malawi (Brune et al. 2016; Dupas et al. 2017), and Uganda (Dupas et al. 2017). However, if takeup only includes people who make at least one deposit beyond enrollment, the engagement rates are only between 18-32% in these studies[9]. Dupas et al. (2017) take stock of 16 completed randomized trials of savings products in

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[7] See further discussion of the breakdown of the products, take-up rates, and impacts for these agricultural credit experiments in Magruder 2018).

[8] In this case increased use of fertilizers, pesticides, and labor.

[9] Dupas et al. (2017) attribute low usage of the savings bank accounts in Malawi and Uganda to living hand to mouth based on consumption measures and self-reports at endline, and also document that people who live farther from the bank branches used the

13 countries, concluding that "few products appeal to more than a small minority (….) overall, the pattern that emerges, if any, is that different features matter for different segments of the population, with no 'one size fits all'" (Dupas et al. 2017).

Where studies specifically engaged farmers and were designed to detect the impact of savings access on agricultural investment, studies have shown that savings helped smallholders smooth volatility (Aggarwal, Francis, and Robinson 2018), build buffer stocks (Carter, Laajaj and Yang 2015), reduce financial pressure from family and neighbors (Batista and Vicente 2017) and increase agricultural productivity investments (Brune et al. 2016; Carter, Laajaj and Yang 2015; Batista and Vicente 2017). Given the prevalence of low take up rates, which interventions can effectively expand access to credit and savings products where these financial services could benefit smallholder farmers? Approaches that show promise tailor credit and savings products more effectively to smallholder farmers' needs and may help reduce the costs and risks to reach this market segment.

3. **Offer flexible collateral arrangements:** Collateral is one classic solution to the asymmetric information problems inherent in credit markets. Unfortunately, many smallholder farmers have few substantial capital assets that they can use as collateral, whether due directly to asset poverty, or to poor property rights. As a result, these farmers have limited liability—meaning that they cannot be forced to repay business loans in full in the case of failure. Land titles are often unclear and seizure under default could be costly and difficult (Jack 2013), constraining credit supply, while on the demand side 'risk rationing' may inhibit poorly insured and diversified farmers from taking the credit risks they are offered, even if expected profits are positive (Boucher, Carter and Guirkinger 2008). Behavioral economics further suggests that farmers may be loss averse, unwilling to risk their land to open a line of credit, given how critical land is for their livelihood and the uncertainty involved and risk of default. Solving credit access problems with land is therefore an uphill struggle.

For technologies that require a large initial investment but retain their value well, self-collateralization through leasing can be an alternative approach to the problem. Under a leasing arrangement, farmers can make payments towards the investment and if they default, the lender can repossess the asset. In Kenya, a dairy cooperative extended asset-collateralized credit offers to smallholders to purchase a large water tank and loan payments were deducted from milk sales. If borrowers failed to repay, the cooperative would repossess the tank. However there were no repossessions among farmers allowed to collateralize 75% of their loans, and only a 0.7% repossession rate among those offered 96% asset collateralization (Jack, Kremer, de Laat, and Suri 2016, see table below produced by J-PAL Africa).

Asset collateralization (rather than large down payments and joint liability requirements) increased takeup of the water tank from 2.4% to 41.9%. Smallholder households that received this loan offer showed reductions in the time children spent on agricultural activities: boys spent less time tending livestock, and girls both spent less time fetching water and were more likely to be enrolled in school as a result.

Group	Deposit	Guaranators	Asset Collateral	Take-up	Repossession Rate
Status quo	33%	100%	None	2.4%	0%
Asset collateral - low	25%	None	Tank	27.6%	0%
Joint liability	4%	21%	Tank	23.5%	0%
Asset collateral - high	4%	None	Tank	44.3%	0.7%

accounts less. Aggarwal, Francis, and Robinson (2018) is an exception to these engagement rates, but the intervention itself is distinctly different from savings accounts at banks, instead introducing a grain storage savings scheme built into existing ROSCA groups in Western Kenya. Take-up rates and impacts are summarized in the section on adjusting products to the seasonality of farmer livelihoods.

Another flexible collateral arrangement allows smallholders to use stored crops as collateral to secure a loan, using warehouse receipts to guarantee claims. These crop inventory loans can also encourage higher take up of credit, and have been shown to increase use of purchased agricultural inputs in Burkina Faso where preliminary results also show promising indications of increased household consumption as a result (Delavallade and Godlonton, in progress). In Kenya, harvest-time maize storage loans did not increase agricultural input use, but did significantly increase smallholders' profits through temporal arbitrage, by allowing farmers to hold on to maize longer and sell only after prices rose (Burke et al. 2017)[10].

These evaluations show proof of concept for both asset-collateralized and inventory credit schemes. However, new credit schemes using these in-kind collateral arrangements should not assume they will be immune from threats to credit demand. Limits to the demand for new credit products can stem from lack of financial literacy or trust, the uncertainty of future in-kind collateral value, particularly in volatile markets (Boucher, Carter and Guirkinger 2008), or prohibitively high "switching" costs to engage in new lending or related trading relationships (Casaburi et al. 2014)[11].

4. **Improve credit market information:** Where physical collateral is lacking, helping borrowers build reputational collateral can unlock access to credit. Without credit histories, banks cannot identify risky borrowers, and often lack viable recourse to recover their losses. Deserving and profitable borrowers could be screened out of the credit pool, suggesting that expansion of credit rating services may improve access to credit. Evaluations of related informational innovations on borrowers include biometric identification (Giné et al. 2010), credit bureaus (de Janvry et al. 2010), and "agent-intermediated lending" which incentivizes agents to identify productive, low-risk individual borrowers (Maitra et al. 2017). These studies show proof of concept for these informational innovations to improve credit market performance, including repayment rates, especially where national ID systems were lacking. Additional research is needed to understand the viability of this approach in different credit markets, and how these interventions could impact farmers' overall credit portfolios and agricultural investment decisions.

5. **Adjust financial service schedules to accommodate the seasonality of smallholders' livelihoods:** Farmers' income tends to be very lumpy and uncertain; many smallholders produce only a few crops for sale and will not see agricultural income materialize until harvest times when harvested crops can be sold. When harvest eventually arrives, all smallholder producers sell in the same time interval. This floods local markets with supply, lowering the prices for these staple grains in typically poorly integrated rural markets where geographic re-distribution to meet urban consumer demand is costly.[12] As a result, prices are lowest immediately after the harvest and peak before the next harvest (Burke et al. 2017). Without access to liquid capital from savings or credit products, farmers face pre-harvest hungry seasons where they are primarily consumers, precisely when prices have risen often to their (annual) peak due to limited supply. This "selling low and buying high" can drain limited resources, perpetuating a cycle of poverty including hungry seasons where there are limited buffers or opportunities to smooth this seasonal volatility. This volatility similarly makes saving challenging, particularly for agricultural purchase investments that would typically be made some time after the

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[10] (Burke et al. 2017) is discussed in greater detail in the upcoming section as a clear example of how the careful timing of product offers and loan repayment schedules is key to support smallholder farmers.

[11] The section on Input & Output Markets will describe in greater detail how producers' relationships with traders can be important mediating factors to access financial services.

[12] See discussion and related literature on poorly integrated markets in the section on Input and Output Markets.

harvest in preparation for planting and growing season activities. For this reason, implementers that do offer credit to smallholder farmers may offer planting and growing season loans that provide access to capital at periods of key agricultural investments while allowing farmers to delay repayment of a loan until after the harvest.

Seasonal price fluctuations can create an opportunity for harvest-time storage loans to help farmers smooth consumption and even generate profit from intertemporal arbitrage. Burke et al. (2017) estimate that the median household in their sample in Western Kenya appears to be giving up equivalent of 1-2 months of agricultural wages by selling maize when prices are low and buying when they are high, instead of the reverse. These researchers partnered with One Acre Fund to offer harvest-time loans collateralized by stored maize, allowing farmers to borrow as a function of the number of bags they put in storage. 63 percent of farmers took out a harvest-time maize storage loan, which were on average about $100 with a 10% flat interest rate and repayment expected in 9 months. Access to this harvest-time storage loan allowed farmers to store maize when prices were low, use the loan to meet their present consumption needs, and postpone maize sales until prices rose to generate higher returns (Burke et al. 2017). Their figure below shows one facet of their preliminary results: that October loan offers, when prices were lowest, were more effective at increasing maize inventories, net revenues, and total household consumption than January loan offers (i.e. when prices were already rising, about midway toward their peak)[13].
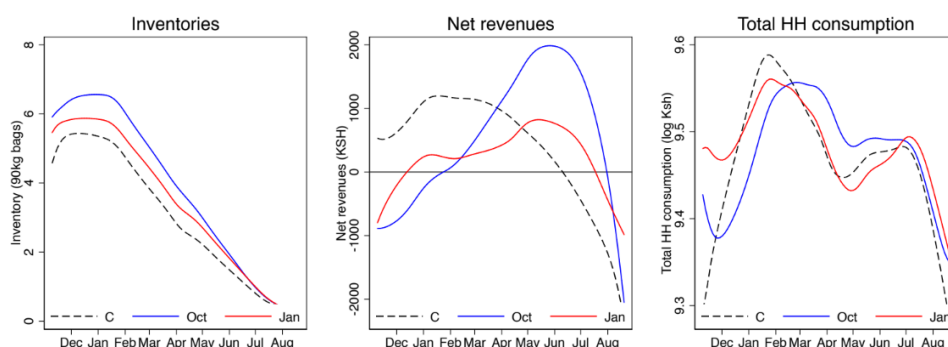
By randomizing the density of treatment across locations, researchers find that profits are concentrated in areas where fewer farmers were offered loans. Though borrowers in less-saturated areas captured larger returns, the presence of the credit intervention smoothed seasonal price fluctuations enough to reduce volatility for everyone buying and selling maize in these poorly integrated markets, effectively spreading benefits even to households in these communities that did not themselves access the storage loans. The estimated 28% return on investment encouraged One Acre Fund to consider scaling this maize storage loan in East Africa.

A savings scheme that similarly targeted volatile maize prices in Kenya used existing ROSCAs to introduce a group-based grain storage scheme ("GSRA"), allowing participating members to deposit a fraction of their maize harvest to be sold later in the season after prices rose (Aggarwal, Francis, and Robinson 2018). Each GSRA identified a member to store group maize bags on a wooden stand in their home (typically the treasurer or other leader of the group) and received a ledger book to record deposits and withdrawals. "About 56% of respondents took up the products. Respondents in the maize storage

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intervention were 23 percentage points more likely to store maize (on a base of 69%)," selling later and at higher prices than those that were not using the GSRA (Aggarwal, Francis, and Robinson 2018).

Loans for consumption during the lean season can help bridge the time when food prices are high and home grain stores are depleted because the harvest has not yet arrived (Basu and Wong 2015). In Zambia, smallholder farmers facing the annual peak hungry season engage in wage labor contracts on local farms, i.e. "ganyu," to make ends meet. When offered a subsidized loan during the hungry season, whether as cash or maize with repayment due after harvest, over 98% of eligible households opted to borrow with 80-94% repayment rates, which improved their hungry season consumption and reduced both their use of higher interest informal loans and their selling of household labor to others' fields. Those receiving the loans were more likely to invest labor in their own fields, which increased their agricultural output by 8 percent in response to treatment, even without inducing additional agricultural input usage like fertilizers, while also raising the average village-level wage labor daily earnings by 15 percent (Fink, Jack, and Masiye 2018). This pilot intervention was expensive, particularly the in-kind maize loan, so researchers are currently exploring opportunities to test a more cost-effective design of the program at scale embedded within a contract farming outfit in Zambia.

6. **Design financial products to overcome behavioral biases and help protect savings from spending pressures:** Financial product design adaptations that target behavioral biases have also shown promise. Helping farmers save for inputs from harvest until planting time, including nudges to behavior to overcome time inconsistency (Duflo, Kremer and Robinson 2011) can increase purchase of agricultural inputs. Allocating resources for particular purchases at particular times using labels or commitment devices can direct investment toward these purchases. In Malawi, Brune et al. (2016) found that farmers given the option of a commitment savings account, designed to help delay withdrawals from the account until input-purchasing season, preserved greater amounts of savings throughout both the harvest and planting seasons, cultivated significantly more land, invested more in agricultural inputs, and increased their consumption. An experiment currently in the field in Rwanda is exploring ways to increase demand for commitment savings accounts while also providing farmers recourse when facing emergencies (Jones, Kondylis and Mobarak, in progress).

Issuing loan capital or input subsidies to farmers as vouchers for agricultural inputs has been a common technique to direct capital toward agricultural investment (Carter, Laajaj and Yang 2016; Duflo, Kremer and Robinson 2010; Giné et al. 2010; among others), although takeup of input subsidy vouchers can be low, possibly signaling that other constraints are binding technology adoption in such contexts (Carter et al. 2013). In Mozambique, Batista & Vicente (2017) tested whether providing input vouchers as a bonus rewarding the use of mobile savings accounts increased savings and fertilizer use[14]. Farmers that received the commitment savings bonus were 31-36 percentage points more likely to use fertilizer if they only received a bonus, compared to 40-41 percentage points more when their social network also had access to the savings bonus. The authors interpret these findings as evidence that these savings accounts decreased social pressure to share resources, given farmers were less likely to lend money to their closest farming friends. This is consistent with social pressures to spend observed by Goldberg (2011) in Malawi.[15]

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[14] Randomly assigned farmers received a 20% savings bonus on their average savings balance, paid out as a voucher for urea fertilizer. Another group of farmers had two of their closest friends also receive information about mobile money and fertilizer, and a final group had both the savings bonus and information given to friends.

[15] The study measures differences in spending windfall income between farmers who win a public lottery, compared to farmers who win a private lottery. She finds that "public winners spend 35 percent more than private winners in the period immediately following the

7. **Financial service provision should be carefully considered alongside risk mitigation:** While tailored financial product designs can better serve smallholders, increasing access to credit in isolation from addressing the risk that farmers face is unlikely to be effective in encouraging agricultural technology adoption. Some initial evidence suggests that for smallholders, a lack of traditional credit is not the primary constraint to becoming more profitable. In northern Ghana, results from a randomized evaluation suggest that the risk of crop failure deters smallholders from making investments in their farms, which contributes to low yields and profits (Karlan et al. 2014). When offered rainfall indexed insurance, more than two-thirds of farmers purchased it and farmers cultivated more acres, used more inputs that boosted yields, and spent more time working on their farms. In Odisha, Emerick et al. (2015) find that smallholder farmers that received the flood-tolerant rice variety Swarna-Sub1 invested in a more labor-intensive improved planting practice, more agricultural inputs (fertilizer), and were 36% more likely to use credit the second year, typically offered from local cooperatives early in the growing season. This effect can plausibly be explained either as a result of increased demand or supply side responses in the credit market (Emerick et al. 2015). These evaluations show that when households are released from risk constraints they can find the capital from sources available to them to substantially increase investment.

LOOKING FORWARD

Although the experimental evidence suggests that an injection of credit alone is unlikely sufficient to transform smallholders' livelihoods, there is some encouraging evidence from approaches with careful product design. Financial service design innovation, particularly to encourage storage or savings, can generate more supportive services for farmers that can help them make investments or manage their volatile livelihoods. There is policy appetite to identify whether digital financial services will be able to connect rural borrowers to lending institutions (Francis, Blumenstock, & Robinson 2017) and encourage financial behavior conducive to agricultural investment. More research is needed on these digital financial service channels and product designs, to understand their potential to support farmers' financial portfolios in a manner that protects farmers while encouraging profitable investments. More research is needed to develop and test credit product designs and delivery channels that fit smallholders' needs with respect to the timing of offers, repayment structures, and collateral agreements.

RISK

MOTIVATION

Smallholder farmers have limited buffer stocks to cope with volatile food prices and climate uncertainty, and typically have few formal financial services to protect them from risk. The systemic risks of agricultural production jeopardize smallholder farmers' ability to recoup their investments at harvest. Risk exposure therefore plays an important role in farmers' agricultural investment decisions, including the use of productive inputs like fertilizer (Dercon and Christiaensen 2011).

Rural communities have developed many informal mechanisms to cope with risk. For example, households may buy or sell assets in response to fluctuations in income (Rosenzweig and Wolpin 1993), and communities may temporarily assist households experiencing a negative shock like an unexpected medical expense with the expectation that the household will do the same for others in the future (Conning and Udry 2007). While these

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lotteries (…) consistent with a seven percent tax on surplus income in a simple model where a fraction of money that is not spent immediately must be shared with others in the social network" (Goldberg 2011).

strategies are useful, in many cases they are insufficient. Farmers face many sources of uncertainty beyond weather and environmental factors including natural disasters, pests, and disease. Price risk and relationships with output markets can jeopardize farmers' ability to recoup their investments at harvest, and such risks can depress productive input use. In addition to the risks inherent in the agricultural production status quo, new technologies often bear specific risks, such as uncertainty about how to use the technology correctly and how to market the output[16].

The classic economic view of poor farmers is that their lack of savings and other resources to fall back on causes them to prefer agricultural approaches with more reliable, but lower, average returns. Households often diversify their sources of income to spread around risk (Banerjee and Duflo 2007). Farmers may see the adoption of new technologies as risky, especially early in the adoption process when proper use and average yields are not well understood. Technologies that carry even a small risk of a loss may not be worth large expected gains if risks cannot be offset (Boucher et al. 2008). Higher-value crops including produce and cash crops may also be more sensitive to weather. So, while investments exist that could increase profitability, these may also increase the risks of farming.

Behavioral biases also come into play around risky decisions (Kahneman 2003). Risk averse farmers may prefer a more certain, but possibly lower, expected payoff over an uncertain payoff from unfamiliar technologies. Ambiguity aversion can lead farmers to stick to their status quo, preferring known risks with a more familiar probability of gains and losses, rather than unknown risks, even in cases where these choices may actually be less risky. Both risk and ambiguity aversion are important considerations when looking to encourage take-up of novel risk mitigating financial products or technologies (Bryan 2010, Hill et al. 2011 and Ross et al. 2012).

Evidence exists that rural households are able to mitigate idiosyncratic risk (Bardhan and Udry 1999), but that rural residents are relatively unprotected against aggregate risks – weather and crop price shocks – common to smallholder rain-fed agriculture in poorly integrated markets (Conning and Udry 2007, Fafchamps and Hill 2008, McIntosh et al 2017, Mobarak and Rosenzweig 2014 and Emerick et al 2016). Given extreme weather events can destroy a large portion of harvest across a region, and that such weather events are only increasingly likely given global trends including climate change, there is a need for effective risk-mitigation strategies to protect farmers from these aggregate risks.

EXPERIMENTAL EVIDENCE SUMMARY:

INSURANCE PRODUCT DESIGN AND RISK-MITIGATING TECHNOLOGIES

1. **Individually marketed rain-index insurance products suffer from very low demand from smallholders; substantial subsidies are required to generate strong insurance demand:** One common risk mitigation strategy is insurance. Developed countries have widespread agricultural insurance coverage that is in many cases compulsory and highly subsidized, and often indemnity based, requiring insurers to visit farms to verify loss claims (IBRD 2010). In developing countries there are far more smallholder farmers dispersed in rural areas with small landholdings operating in poor regulatory environments. Weather index insurance, making payments to farmers in a specified area based on levels of an observable variable like rainfall, decreases administrative costs to insure smallholders.

   However, field experimentation shows that few farmers purchase individually marketed rain-index insurance policies at market prices.

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[16] These types of risk are discussed further in the sections on Information and Input & Output Markets, respectively.

"Index insurance products struggle to launch without heavy initial subsidies, and results are consistent with substantial lack of trust in index insurance" (J-PAL, CEGA, and ATAI 2016, includes figure below).

DEMAND FOR INDEX INSURANCE WAS LOW AT MARKET PRICES BUT INCREASED WITH LARGE DISCOUNTS
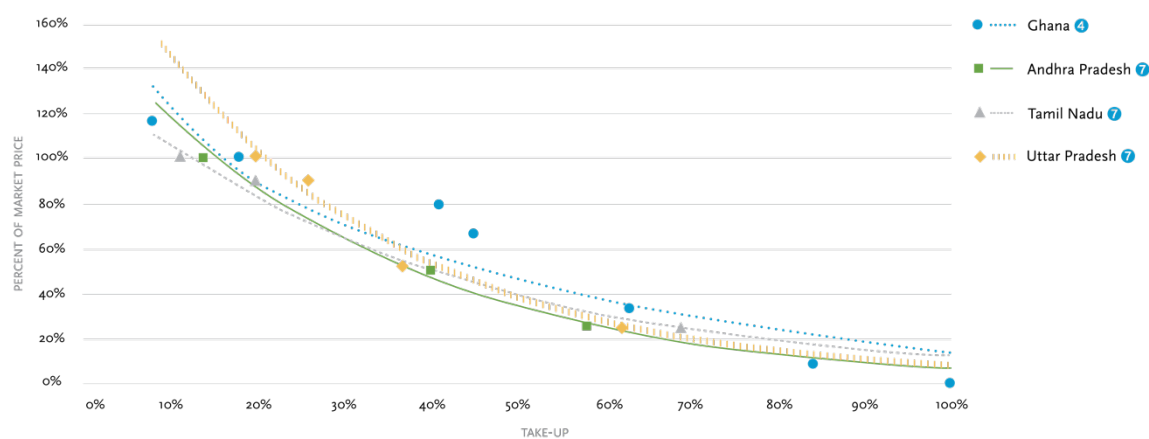
Two studies (4 and 7) randomly offered discounts to customers, generating enough data to estimate demand curves for weather index insurance.
Demand was low—below 20 percent—at market prices but increased when farmers were offered large discounts.

Few products have succeeded in sustaining demand in the developing world with prices set at market rates, above actuarially fair prices -- full market price typically yields an uptake of around 16%, and even a 50% subsidy only increases demand to 38% (Mobarak and Rosenzweig 2012, Karlan et al. 2014 and Cole et al 2013; 2014). As a result, these products do not appear to be commercially viable as standalone products.

2. **Financial education, group protection, and links to credit have not proven viable options to improve insurance demand:** "Linking credit with insurance has mixed results, suffering from the same demand problems that have beset standalone index insurance. The offering of indemnified loans that interlink an insurance product with credit appears promising, but demand for such loans has been shown to be surprisingly low in the few trials that have tested this mechanism (McIntosh et al. 2017, Giné and Yang 2009, Karlan et al. 2014 and Karlan et al. 2011)" (J-PAL, CEGA, and ATAI 2016). Linking credit with insurance has even been shown to drive down credit demand (Banerjee et al. 2014[17] and Giné and Yang 2009).

    Recent research has found that companies that engage in contract farming can be well-positioned to adjust the timing of insurance and payment arrangements to increase take-up. Casaburi and Willis (2017) find that when a large private company engaged in contract farming in Kenya offered to provide insurance to sugar cane producers by deducting premiums from farmer revenues at harvest time, take-up rates at actuarially fair prices were 71.6%, 67 percentage points higher than the equivalent standardly timed contract.

    Although farmers' trust and understanding surely influences demand for weather index insurance, resolving these concerns has not proven sufficient to solve the demand issues that beset this financial product. Demand for insurance does increase when farmers observe payouts over time (Cai et al. 2016 and Karlan et al. 2014); receiving payouts in the previous year has a strong effect on increasing

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[17] Banerjee et al. (2014) investigates demand for health insurance, rather than agricultural weather-index insurance.

subsequent demand, increasing demand by almost 30% (Cole et al. 2014). However, not receiving payouts when a fair price has been paid has a strong negative effect on subsequent demand. Since the latter state is the 'normal' year for insurance consumers, this does not bode well for the adoption of insurance and its commercial viability. Cole et al. (2013) explicitly tests whether efforts to improve trust can improve take-up of insurance, finding that "in Andhra Pradesh, households were more likely to purchase insurance if an agent from a well-known microfinance institution endorsed the product, but in Gujarat, a similar endorsement in a marketing video had no effect" (J-PAL, CEGA, and ATAI 2016). In another study from Gujarat, Gaurav et al. (2011) found that receiving an invitation to a financial literacy training increased take-up by 5.3 percentage points, but the cost of the training was more than three times the full cost of premiums.

Basis risk, the risk that the official weather observation will not accurately reflect a farmer's loss, can also dampen take-up. For example, a farmer may experience poor weather conditions that damage their harvest, but if rainfall at the weather station is adequate, there would be no pay out. Mobarak and Rosenzweig (2012) find in Uttar Pradesh that for every kilometer increase in perceived distance from the weather station, demand for weather index insurance decreases by 6.4% (approximately equivalent to 10% less of a discount from the market price). This suggests that improvements in index design could help resolve basis risk, using improved data to more closely align the experienced conditions of smallholders' plots with the measured conditions at data collection facilities (like rainfall at weather station locations) used to set the index. Since basis risk is largely covariate for a geographic area, another promising approach appears to be the provision of insurance to groups that are already providing informal risk pooling of idiosyncratic risks among their membership (Dercon et al. 2014; Mobarak and Rosenzweig 2012). Index insurance can be a complement to informal risk mitigation where these informal risk pooling arrangements are smoothing idiosyncratic risks.

3. **Adopting insurance can increase risk-taking in production decisions:** Where insurance projects have been successful in achieving widespread uptake (largely via free distribution) they tend to increase the appetite for activities vulnerable to risk (Cole et al. 2013, Mobarak and Rosenzweig 2012, Gunnsteinson 2014, Cai et al. 2009 and Cai 2016). Magruder (2018) emphasizes, however, that these studies are "a handful of promising results that suggest the potential for risk reduction to spur technology adoption," necessarily drawn from exceptional contexts where insurance take-up rates were sufficient to detect the impacts of insurance on productive technology adoption. This shift to higher risk and potentially more profitable production can have the somewhat counterintuitive effect of increasing the overall exposure of agricultural activity to rainfall volatility. Insured households are better financially insulated (Janzen and Carter 2018), but landless laborers, whose income relies on harvesting crops, may become more exposed to risk as a result (Mobarak and Rosenzweig 2014). This is concerning if the poorest rural households have limited alternatives should agricultural wage labor opportunities disappear.

4. **New risk-mitigating crop varieties provide a promising alternative or complement to insurance that can reduce farmers' risk and produce higher yields:** Scientists have developed stress-tolerant crops to protect farmers and help the broader agricultural system cope with extreme weather. These breeder-selected varieties of common seeds are agronomically designed to maintain high yields if a drought or flood occurs. Dar et al. (2013) conducted a two-year randomized evaluation with the International Rice Research Institute (IRRI) to study the effects of a flood-tolerant rice variety, Swarna-Sub1, on rice yields and farmer behavior in Odisha, India. Switching from Swarna to Swarna-Sub1 cultivation does not require significant changes in farmer behavior. Flood-tolerant Swarna-Sub1 rice reduced risk for smallholder farmers and encouraged additional investment in their farms, resulting

in substantially increased yields in both flood and non-flood years (Dar et al. 2013). Yields of this flood-resistant rice variety were as good as regular varieties in normal conditions and superior during floods, and the yield gain went disproportionately to low-caste farmers because of the less-desirable risk-prone location of their lands due to generations of social marginalization (see Figures 1 and 2, at right, from J-PAL, CEGA, ATAI 2015). Higher yields increased farmers' revenue by approximately US$47 per hectare relative to farmers in comparison villages, and 36% of this additional revenue was reinvested in their land. The results show how farmers respond to risk reduction by crowding in other investments and technological changes, which effectively double farmers' expected gains: first from the agronomic benefits of the improved seed itself, and an equal

FIGURE 2. THE YIELD ADVANTAGE OF SWARNA-SUB1 INCREASES WITH MORE DAYS OF FLOODING
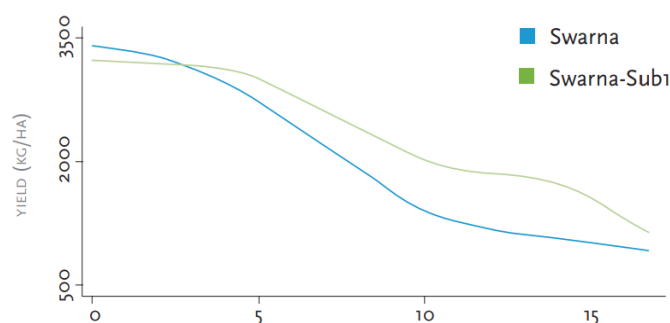
FIGURE 3. LAND HELD BY MEMBERS OF SCHEDULED CASTES WAS MORE LIKELY TO FLOOD
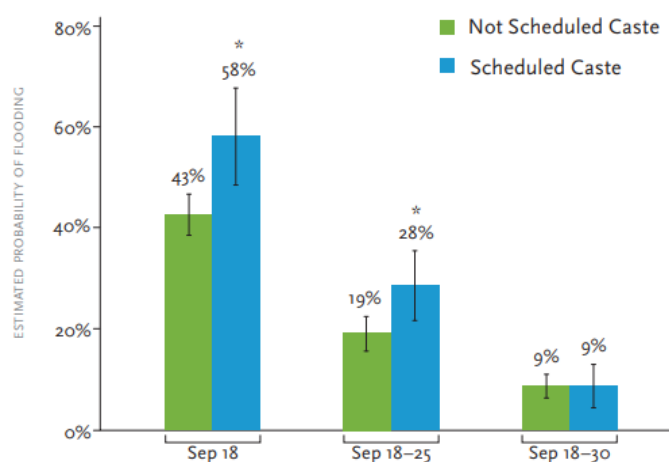
Note: Error bars represent 95% confidence intervals.
Stars (*) note statistical significance from control group.

benefit reaped from unlocking more productive practices when protected from risk. These researchers are now evaluating the long-term effects of Swarna Sub-1, as well as the yield, welfare, and labor market impacts of other drought- and saline-tolerant crop varieties.

Yet longer-term analysis shows that even improved varieties like SwarnaSub1, with demonstrated impacts and effective demand, have not been widely adopted. This shifts attention to other constraints, particularly the importance of seed supply and extension systems for technology diffusion, which will be discussed in the remaining sections in this chapter.

LOOKING FORWARD

Given insufficient demand for individual-level insurance, and the limited availability of agronomic technologies that could singlehandedly protect farmers across a wide range of agro-climatic conditions, ongoing research is focused on adjustments to, and combinations of, these risk mitigation approaches (Carter et al. 2017a). Could institutions engage in risk-sharing to move risk away from particularly vulnerable smallholder farmers? For example, perhaps financial institutions or governments could serve as clients for meso-level insurance to see if that benefits smallholder farmers. "Under this arrangement, [e.g. the World Bank Group's Global Index Insurance Facility (GIIF) and African Reinsurance Corporation (Africa Re) plan], a government or institution would reimburse insurers above a set loss ratio. This decreases risk and costs for insurers and could lead to lower premiums for farmers" (Carter et al. 2017b).

Or, given willingness to pay for individual insurance has been a challenge, perhaps free or subsidized insurance could be offered as a form of social protection, achieving a multiplier effect by releasing farmers' production decisions from risk constraints. Ongoing research is testing strategic combinations of financial products including index insurance, precautionary savings, and emergency credit (i.e. products with explicit or implicit limited liability in case of weather shocks), to understand if these bundled products can protect smallholders across a spectrum of risks of varying severity (Sadoulet, de Janvry, and Lane in progress). Or perhaps financial products could be combined with risk-protective seeds in an attempt to better mitigate risk under a wide range of conditions. An evaluation is underway by Carter et al. (in progress) that offers a combination of drought tolerant maize and index insurance in Tanzania and Mozambique, given index insurance could protect against the extremely adverse events that prove so taxing that even stress-resistant seeds fail (Carter et al. 2017a).

INFORMATION

MOTIVATION

Farmers face a range of potential production technologies and practices to choose from, each of which may have different risk profiles and different suitability for a farmer's own plots. Many technologies have heterogeneous returns that vary based on local plot characteristics and complementary input choices or agronomic practices (Glennerster and Suri 2017; Tjernström 2017). In addition, any single year farmers can only observe the performance of the technology under one weather realization, and understandably have trouble predicting outcomes under a range of different conditions they could experience in the future. A variety of specific information is therefore necessary for farmers to make good decisions as to which technologies to use at which specific points in time.

Extension services have been a common approach used to inform farmers and encourage technology adoption, and have traditionally been one of national agriculture ministries' main types of expenditure (Goyal and Nash 2017; Davis 2008). The available literature has compiled summary statistics on the type of learning outcomes that we should hope to see as a result of large investments in extension systems. These statistics match anecdotal understanding that often status quo extension systems are characterized by limited supply of extension agents in communities, and even where available, low engagement with services, low adoption of recommendations, as well as low information diffusion beyond a select few contact farmers (Blair et al. 2013; Cunguara and Moder, 2011; Kondylis et al. 2017; Waddington et al. 2014; Beaman et al. 2015b).

Extension workers are often expected to cover large areas with limited staff. For example, in Mozambique, countrywide extension coverage is as low as 1.3 agents per 10,000 rural people (Coughlin 2006), while in Malawi approximately 50% of government extension positions remain unfilled (BenYishay and Mobarak 2014). Glendenning et al. (2010) estimated that fewer than 6% of the agricultural population in India reported having received information from the Government of India's decades-long extension program. Extension workers may simply shirk responsibilities, or choose to focus their attention on villages or individuals based on their convenience to reach or perceived potential (Coughlin 2006), and may neglect more marginalized farmers from poorer (Alwang and Siegel 1994) or female-headed households (Saito 1994). Rural extension services are difficult and costly to monitor, limiting the potential to hold extension workers accountable and providing little direct incentive to show up for work or complete their duties (Anderson and Feder 2007).

Duflo et al. (2008) shows another, perhaps intuitive, reason that extension can be ineffective – if it is promoting the use of a technology that is not profitable. They found that test plots using fertilizer recommendations from the Kenyan Ministry of Agriculture did not encourage fertilizer adoption by farmers. In this case, Duflo et al. calculate that these fertilizer recommendations would have increased farmers' yields if applied, but would have

actually reduced farmer profits. For food security and broader economic reasons, governments are often interested in maximizing yields, and thus extension programs may make regional-level fertilizer and other input use recommendations that target yield outcomes that farmers disregard as unlikely to be profitable. Gearing extension service recommendations based on what is profitable is important to drive adoption.

Traditional extension models that directly train "contact" farmers typically do so given budget limitations, in the hopes that these contact farmers will share information and encourage new practices among other farmers. Analyses of panel data suggest that farmers learn from observing the decisions and experiences of people in their social networks (Foster and Rosenzweig 1995; Bandiera and Rasul 2006; Munshi 2004; and Krishnan and Patnam 2013). Conly and Udry (2010) in particular examine the importance of heterogeneity in observable characteristics of demonstrators for the transferability and diffusion rate of a particular technology, and Rogers (2003) discusses how "trialability," the degree to which a potential adopter can try something out on a small scale first before adopting it completely, can also be an important factor for adoption.

We present findings from randomized evaluations that show how agricultural extension can be more effective in both the initial design of channels and pedagogy, and the use of social networks to encourage the spread of technology adoption.

EXPERIMENTAL EVIDENCE SUMMARY:
IMPROVING LEARNING AND TECHNOLOGY DIFFUSION

1. **Information services are important when introducing truly novel and unfamiliar technologies that can improve farmer welfare:** Getting extension right is particularly important in contexts where farmers are not familiar with the improved technology and may have limited access. Extension systems were shown to be important when providing access to and promoting a new crop variety (Emerick and Dar 2017), particularly when farmers will need to shift complementary agronomic practices to reap the benefits. Glennerster and Suri (2017) conducted a randomized evaluation in Sierra Leone of the roll out of NERICA-3, a faster-maturing rice variety that can quicken harvest times for food insecure households but requires shifts in production behavior, in this case unfamiliar labor schedules and practices. Results suggest that training helped in this context: yields only increased for farmers who received extension services alongside free seed kits, while those who received the new seed without training saw a decline in yields (though small and statistically insignificant) (Glennerster and Suri 2017).

   Research is still needed on how to effectively provide farmers with information in the context of truly new technologies. Open questions include how to encourage adoption of new varieties that require new complementary behaviors in order to reap the benefits.

2. **Use simple and accessible channels, provide timely guidance, and focus on important aspects that are difficult to observe:** To help farmers better use available, even familiar, technologies, information services should identify margins where behavior change may be difficult to modulate or even seem counterintuitive, but optimization could generate welfare benefits. Farmers may make sub-optimal decisions over long timeframes as a result of common behavioral biases, such as procrastination (Duflo et al. 2008), that hinder optimal decision-making. Certain aspects of production that are difficult to observe and learn from can be important inputs to farmers' decision-making. For example in Bali, Hanna et al. (2014) engaged seaweed farmers in experimentation to "learn by noticing"

the outcomes from planting different seed pod sizes, a specific dimension for which they were not previously attentive. Participating in the trial by itself had little effect on adoption of improved practices, but when farmers also received a summary of the trial results on their plot, their adoption of these improved practices increased.

Fertilizer application is an example of a particularly complex decision that can benefit from specific and timely recommendations given there are a variety of types, quantities, and timing to consider for application. A range of simple and direct tools have been found effective by helping farmers identify the most important dimensions of fertilizer application in their context. Duflo et al. (in progress) find that in Kenya, giving farmers measuring spoons led to higher fertilizer adoption. Islam (2014) finds that providing farmers with leaf color charts in Bangladesh significantly decreased the amount of excess urea fertilizer used (by 8%) and improved timing in application, increasing yields by 6.8%.

ICT-enabled mobile extension can be designed to effectively improve contact with farmers with reduced costs to tailored, frequent, and timely information sharing. An interactive voice response system, at the time called Avaaj Otalo, provided timely information on weather and inputs as well as specifically answering farmers' questions about agronomic practices. A randomized evaluation found that farmers switched to more effective inputs, dedicated more land to cash crops, and saw increased yields (Cole and Fernando 2018). The Avaaj Otalo hotline particularly helped farmers switch to less visually appealing, but more effective pest management, and impacts were greater for the group that received reminders at specific times aligned with growing season activities (Cole and Fernando 2018). Among contracted sugarcane farmers in Kenya, one-way SMS agricultural advice and reminders throughout the planting, growing and harvesting cycles combined with a complaint hotline led to increased fertilizer usage and reduced non-delivery of inputs (Casaburi et al. 2014, preliminary).

3. **Social networks play an important role in driving adoption:** Farmers learn from observing the decisions and experiences of people in their social networks. For example, the previously discussed Avaaj Otalo experiment shows some evidence suggesting that intervention group farmers shared information with their peers that affected their agricultural activity. Peer farmers with more ties to participants in the mobile advisory service were more likely to plant the cash crop cumin and less likely to lose crops than less-connected households (Cole and Fernando 2018). This shows that other farmers can be an important source of information about new technologies.

    But social learning is not automatic, and the selection of extension agents and lead farmers tasked as communicators can result in different learning outcomes (Kondylis et al. 2017). Social learning can be stunted if the personal benefits are insufficient to encourage information sharing (BenYishay and Mobarak 2015). Learning from others can also result in a less rapid spread of technology if social networks are segregated or small. Beaman and Dillon (2018) find that in Mali, targeting network central farmers with information on composting excluded less-connected farmers, particularly women. Emerick (2014) demonstrates similar limitations to the inclusive diffusion of technologies – when targeting the adoption of an improved rice variety in Odisha that had an estimated positive return for 84% of sampled farmers, relying on de facto social network distribution alone led to only 7% adoption, well below the demand elicited through door-to-door sales (40% adoption of the variety). By limiting seed transactions to contacts with close peers, households with smaller caste and family networks were less likely to adopt the technology (Emerick 2014). In this context, introducing outside buying and community-wide training opportunities can be critical to encourage the diffusion of new technologies. Indeed, Emerick and Dar (2017) found that a simple two-hour field day to observe and hear about experiences and outcomes with the new rice variety led to a large increase in seed adoption (from 30%

to 42% adoption), with the effect significantly larger for farmers below the poverty line and from lower caste groups. These findings "suggest that field days reduce the barriers to information transmission, regardless of the identities of the demonstrators" in this context (Emerick and Dar 2017).

4. **Advice from multiple people is important for adoption:** Beaman et al (2015b) worked with the Malawi Department of Agriculture Extension Services (DAES) to promote pit planting, experimentally evaluating the selection of trained farmers using social network mapping, finding that this achieved much more technology diffusion compared to business-as-usual extension agent selection of trainees. Researchers estimate that 70% of people needed to see at least two connections to be persuaded to adopt the technology. Tjernström (2017) also finds evidence from Kenya that farmers are more likely to demand a new technology if a greater proportion of their network is observably using it. Extension modalities may therefore need to be adjusted to train enough contact farmers in each village, given multiple lead farmers may be needed to induce technology adoption. These studies suggest that a minimum intensity of exposure to spur adoption should not be diluted in efforts to spread limited resources to achieve exposure equity.

5. **Farmers are more likely to follow advice from demonstrations that reflect their own characteristics:** Communicators that more closely resembled target farmers' own demographic and socio-economic circumstances were more effective at promoting a new technology in Malawi (BenYishay and Mobarak 2014). This has important implications given discrimination against women: although BenYishay et al. (2016) found that female communicators in Malawi learned and retained information better than men, and the farmers they taught experienced higher yields, these female "lead farmers" were less successful at teaching or convincing others to adopt new agricultural practices. Micro-level data on individual interactions from 4000 farmers in these villages suggests that "other farmers perceive female communicators to be less able, and pay less attention to the women's messages."

Greater similarity of demonstrators and learners matters not only in regards to the demographics of demonstrators, but also their agro-climatic conditions (Kondylis et al. 2017). Although Tjernström (2017) finds peer learning effects in the adoption of improved maize in mid-altitude Kenya, villages with more variation of (unobservable) soil nutrients were less likely to adopt an improved seed based on peers' experience. So, heterogeneity seems to dampen social learning. Ongoing research conducted by Precision Agriculture for Development, for example, is targeting key outstanding questions about cost-effective delivery of sufficiently tailored input recommendations that can benefit more farmers.

Personal experimentation, allowing farmers to test and observe the outcomes of technology adoption under their own circumstances, may be particularly useful in contexts of heterogeneity. Dupas et al. (in progress) are rigorously testing the extent of personal experimentation and diffusion of information and technology use based on which farmers are selected to receive an irrigation hip pump in Western Kenya. Forthcoming results will allow for a comparison of technology diffusion when contact farmers are chosen based on willingness to pay for the technology, willingness to work (in the case of liquidity constraints), those voted by the community to receive the technology first, or those selected at random via a lottery, given the implications for targeting extension and distribution programs.

6. **Incentivizing extension agents can induce higher engagement with harder-to-reach clientele, and performance-based incentives tied to learning outcomes can increase technology adoption:** Given the costs of serving distant rural populations and the challenges to deploying effective agents, we look to evidence on incentivizing financial service and extension agents to

improve outcomes – a version of pay for performance. In the context of encouraging the adoption of novel financial products, Cai et al. (2009) found that incentivized extension workers were significantly more effective at promoting sow insurance in rural areas, while Maitra et al. (2017) used incentivized agents to more effectively target appropriate rural borrowers. BenYishay and Mobarak (2014) show proof of concept for performance-based incentives to improve the performance of agricultural extension agents and lead farmers. The scheme rewarded extension agents and lead farmers in Malawi for increased knowledge among community farmers in year one, and an increase in the adoption of technologies and improved practices among community members in year two. The effects were largest when offered to peer farmers; their effort levels effectively doubled when a bag of seeds served as a small performance-based incentive to improve recipient farmers' knowledge and behavior (BenYishay and Mobarak 2014).

LOOKING FORWARD

Evidence presented in this section shows that well-designed information provision attuned to smallholders' information needs and social networks can encourage poor farmers to invest in new technologies. There is a need to support farmers' decision-making when introducing unfamiliar inputs, and early evidence demonstrates how to adapt information provision systems to support smallholder farmers' in technology adoption.

The inefficiencies that cripple extension systems and lead to information constraints can also impede the physical availability of technologies. In Uganda, Bandiera et al. (in progress) worked alongside BRAC's roll out of their female extension worker model in Uganda to understand how social networks, credit constraints, and expectations about the returns to technology affect adoption decisions of improved seed varieties and modern farming practices such as zero tillage, line sowing, and disease prevention. Increases in agricultural productivity were achieved by effectively targeting the key "accessibility" constraint in this context -- farmers previously had little access to quality improved seeds. However, social connections mediated input market access: extension workers play an important role in selling seeds, and farmers in their networks had better access to technologies compared to less-connected farmers. Emerick et al. (in progress) are extending their work on improved seed and extension in Odisha to understand how agents in input value chains can effectively provide both information and technology.

Given that a lack of information is unlikely the primary constraint to technology adoption where inputs are not locally accessible, and improved quantities, qualities, or varieties of output may not be profitable in current market structures, we turn our attention to supply chains and markets[18].

INPUT AND OUTPUT MARKETS

MOTIVATION

Farmers who would benefit from technology adoption may be unable to access agricultural technologies due to inadequate infrastructure, missing supply chains or unprofitably high prices. Where technologies simply are not available at the local level, clearly the presence and efficiency of input supply chains plays a critical role in technology adoption (Emerick et al, 2015).

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[18] The upcoming section often cites evaluations of information-based interventions. These are included in the section on Input and Output markets given their objective to drive or generate new market equilibria that benefit smallholders.

Output market dynamics can also affect smallholder decision-making. Information about market conditions and prevailing prices could influence farmers' decisions of how, when, and where to sell their harvest, while search and transport costs, and relationships with traders, mediate producers' access to potential points of sale.

In Sub-Saharan Africa in particular, farmers are limited in their ability to access lucrative options for sale (Barrett 2008). The cost of doing business is likely an important factor, although the specific reasons behind high costs of trade for a particular context have been challenging to distinctly identify (Atkin and Donaldson 2015). Measurement challenges make it difficult to distinguish the degree to which long distances, poor infrastructure, policy-driven market distortions, intermediary market power, and relatively limited information and communication technology might contribute to high trade costs in a particular context (Fafchamps, Gabre-Madhin and Minten, 2005). While estimations of transport costs in Africa are clearly high in comparison to other regions (MacKellar et al. 2002; Rizet and Gwet 1998; Rizet and Hine 1993), there is very little causally identified evidence on the competitiveness of trade in Africa (Dillon and Dambro, 2016).

Where trade costs are high, there may be limited spatial arbitrage, making producers reliant on those who have the capacity to access these arbitrage opportunities and act as trade intermediaries (Fafchamps and Vargas-Hill 2005). Rural markets remain poorly integrated when there are limited options for trade, and this inefficient movement of supply results in wide-ranging local market prices across regions and seasons (Rashid and Minot 2010; Moser, Barret and Minten, 2009; Barrett 2008; Gilbert et al. 2017; Aker 2012; among others). This volatility can be a direct disincentive to widespread adoption of productive technologies (Foster and Rosenzweig 2010) because an influx of output is met immediately by a collapse in prices (Burke et al. 2017, see their figure, below, showing the volatility of maize prices in East Africa).
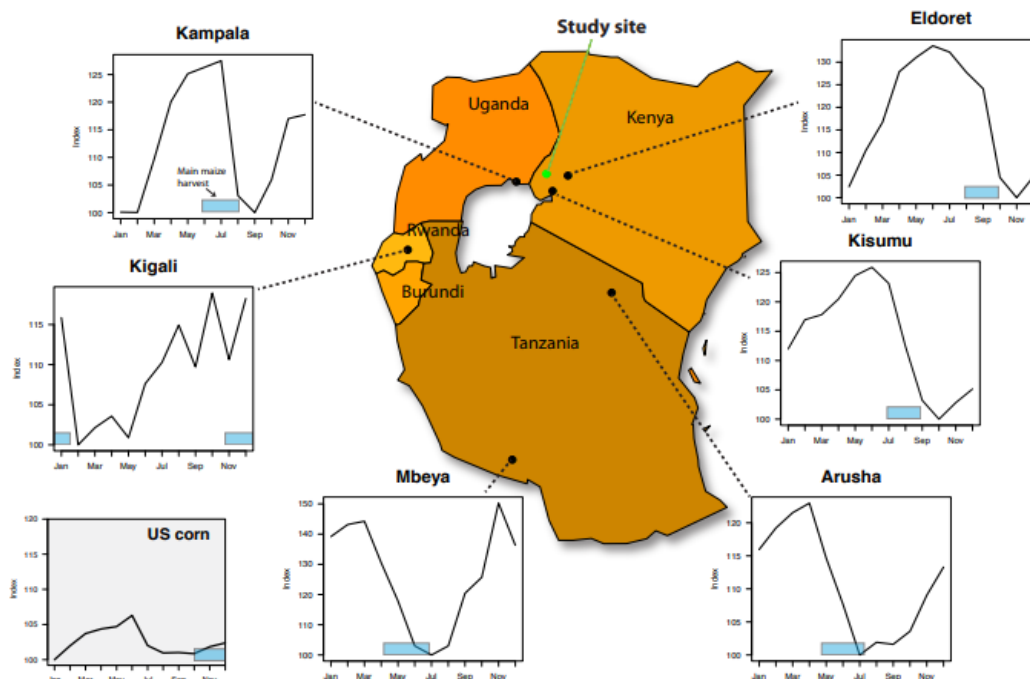
Poor infrastructure has been rigorously investigated in a few cases; road quality, for example could clearly increase transport costs, driving up input prices, driving down output prices, and thereby reducing the scope for profitable adoption of productivity-enhancing technologies. Infrastructure development to reduce transportation costs has been associated with increased access to output markets and smoother prices (Ali 2011). For example, in Sierra Leone, investments in infrastructure were correlated with lower transaction costs for both farmers and traders (Casaburi, Glennerster and Suri 2013). However, farmers' ability and willingness to pay for access to deeper output markets should not be assumed even where road conditions are adequate (Raballand et al. 2011).

Contract enforcement problems in supply chains and output markets can also impede producers' profitability. Buyers may trade only with trusted brokers or other traders with whom they have repeated interactions, resulting in a fractured chain of many short-distance, relationship-based exchanges (Fafchamps and Minten, 1998). The surpluses offered by each small seller may be too diffuse to attract large national buyers, instead requiring aggregation, which often necessitates both coordination and access to capital (Sitko and Jayne, 2014). Unobservable dimensions of output quality can mean higher quality products go unrewarded on the market, resulting in the prevalence of lower quality products (Anagol forthcoming; Hoffman and Gatobu 2014; Fafchamps et al. 2008).

Enforceable contracts could create economies of scale, and facilitate access to technologies, financial services, and output markets for small-scale producers (Barrett et al. 2012, World Bank Group 2016 and Casaburi et al. 2014, preliminary). Hansman et al. (2017) find evidence from Peru fishmeal manufacturing that vertical integration increases with demand for high-quality outputs; firms produce considerably higher output and are paid higher export prices when they own more of their suppliers. These benefits of contracting arrangements could presumably help smallholders access higher-value markets where economic growth in agriculture is increasingly concentrated (Gulati et al. 2007). But evidence is still limited, and there are risks that contract farming schemes can falter or collapse (Ashraf et al. 2009).

In what follows, we describe the recently emerging experimental evidence based on interventions to improve the efficiency of input and output markets in relation to smallholder farmers. We focus on two primary domains. First, price discovery, given the relatively numerous studies that have tried to improve the delivery of price information to producers and intermediaries. We then examine a set of interventions intended to improve contracting in supply chains, including studies that work to improve quality recognition, to improve contracting performance through intermediary institutions, and to create entirely new market structures leveraging ICT platforms.

EXPERIMENTAL EVIDENCE SUMMARY- EARLY INSIGHTS

1. **Price information can lead to a reduction in price dispersion; however, farmers often need more than price information to access more profitable points of sale:** Given that prices may vary substantially across relatively small distances and small intervals of time, accessing price information in principle could lead to larger profits for farmers, by choosing to sell at markets with higher prices (spatial arbitrage) or leveraging price information to bargain with traders.

   The following evidence underlines how price information is unlikely to affect farmer incomes or price levels where farmers lack bargaining power, because transport costs remain high, or there are other limits to output market competition. Potato farmers in West Bengal did not benefit from nearby wholesale and retail market price information given farmers have limited outside options for sale and traders appear to collude by openly discussing and coordinating price offers to farmers (Mitra et al 2018). Fafchamps and Minten (2012) estimate the benefits that Maharashtran farmers derived from market and weather information delivered to their mobile phones by a commercial service called Reuters Market Light (RML), finding some evidence that RML affected spatial arbitrage and crop grading, but that the magnitude of these effects is small and does not significantly affect farmers' other practices or the price farmers receive. As small-scale producers in these contexts, farmers may be limited in their ability to access more profitable points of sale, and have low market power in relationship to intermediaries. Though farmers changed their behavior, there were on average no profit gains for farmers. In a multi-stage experiment designed to understand competition in rural Kenyan

maize markets, Bergquist (2017) empirically demonstrates that low levels of competition among collusive traders lead to an estimated 15% reduction in total welfare. An intervention to introduce small numbers of new traders to local markets had a limited impact on prices, as new traders were incorporated into local traders' collusive arrangements. Bergquist attributes traders' market power to startup costs, a barrier to entry that limits the number of traders, who then collude to pay below-competitive prices to farmers and charge above-competitive prices to consumers. These findings suggest that more fundamental changes that truly unlock new output market options may be needed to enhance competition in such markets. Ghani and Reed (2017) find that increased competition among ice manufacturers in Sierra Leone "leads to substantial improvements in fishermen's productivity and reductions in the consumer price of fish."

However, members of value chains who can act on price information can use price information services to access benefits. The introduction of mobile phones in the Kerala fishing industry dramatically reduced price dispersion and waste, and increased fishermen's profits by 8% and consumer surplus by 6% (Jensen 2007). An innovative procurement strategy that introduced internet kiosks to provide an alternative marketing channel with access to a private buyer, price information, and warehousing services in Madhya Pradesh increased market prices of soya by 1-3%, reduced price dispersion, and increased the area under soy cultivation (Goyal 2010). Quasi-experimental measurement of the effects from improved mass-communication to share price information also show some evidence of reduced price dispersion. In Niger, the introduction of mobile phones from 2001-2006 led to an estimated 10-16% reduction in grain price dispersion, primarily through reduced search costs, with the effect stronger for market pairs with higher transportation costs, and when a large percentage of markets have mobile phone coverage (Aker 2010). Svensson and Yanagizawa-Drott (2009) estimate that providing market price information on maize via FM radio increased farmgate prices by 15% in Uganda. "They show that farmers with better access to commodity price information via radio are able to bargain for higher prices. They exploit variation in access to radio signals in a difference in difference analysis. In their setting, farmers sell surplus production to traders and receive better farmgate prices if they have better access to information" (Jack 2013).

More research is needed to understand how increasing farmers' access to deeper output markets may reduce excessive price risk, open opportunities to improve farmer profits and welfare, while triggering technology adoption. One such competition-enhancing approach facilitating market linkages is currently being evaluated in an experiment in Uganda (Bergquist and McIntosh, in progress).

2. **Quality certification is an important contracting problem:** Quality certification is a contract enforcement problem that is key to the functioning of both input supply chains and output markets. For example, even where inputs may be present at local agro-dealers, concerns about poor-quality inputs may depress technology adoption where regulatory bodies are missing that certify quality and dis-incentivize the sale of faulty or fraudulent products. Bold et al. (2017) was motivated by common anecdotes in Uganda about poor quality fertilizer and seeds. They collected data to understand the magnitude of the problem, revealing empirically that agricultural inputs sold at the retail level in Uganda are often 'fake' or of very poor quality -- the vast majority of fertilizer samples were substandard, and very few of the allegedly improved seeds showed success in producing large crops on test plots (Bold et al. 2017). Farmers' choices were "much more rational than reflexive rejection of modern techniques," demonstrating an important factor contributing to Uganda's extremely low fertilizer adoption rates (6.6%, LSMS-ISA).

Technology-driven quality rating systems can work to deepen information and improve incentives in the input supply chain. A crowd-sourced ICT clearinghouse (like "Yelp") that allows smallholders to rate the quality of artificial insemination (AI) service providers effectively improved the quality of government extension service provision in Punjab, Pakistan (Hasanain et al. 2017, see their Figure 4 at right). Small-scale cattle farmers used the system to submit ratings and understand others ratings and prices to bargain with vets. The system effectively decreased prices and increased service quality (27% higher insemination success), without needing to switch service provider; in fact farmers were 33% more likely to return to a government veterinarian than switch to a private provider. These effects are concentrated on lower ranking vets, who tend to serve more distant

Figure 4: AI success rates in real time—clearinghouse data

farmers. By decreasing information asymmetry, the clearinghouse system led to AI success improvements that were on average equivalent to an additional 50% of one month's median income in this context, a 300% return on the cost of the program.
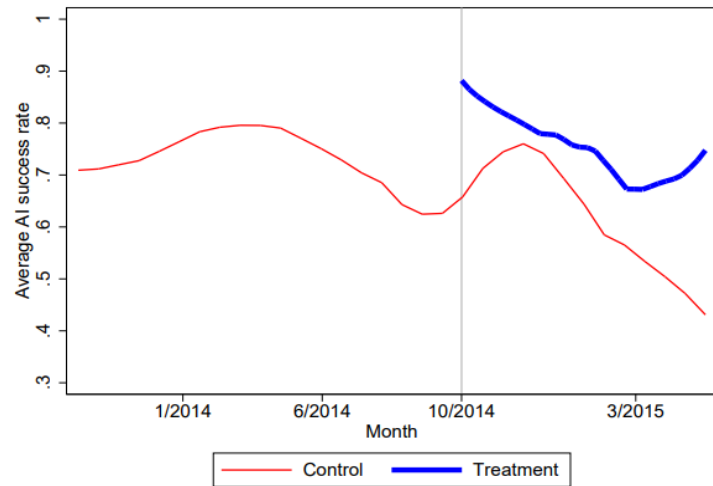
Disorganized output supply chains with multiple intermediaries may fail to properly recognize, incentivize, and certify quality, and as a result, opportunities for farmers to add value are lost. There are limited incentives for producers to invest in higher quality production, particularly on dimensions that are unobservable, if buyers and producers do not trust each other and reputation-building is a challenging and low-return investment (Fafchamps et al. 2008) (Bai 2017). Farmers seem to be most strongly rewarded by the quantity and directly observable characteristics of what they sell, rather than the quality, so external verification may be needed to encourage specific agronomic or other quality-enhancing production practices (Bernard et al. 2017; Hoffmann et al. 2013; Saenger, Torero, and Qaim 2014). Important quality markers may be unfamiliar to farmers, or difficult to observe or costly to verify. On the consumer side, the domestic food supply faces related quality control issues. Failure to resolve these can be detrimental to consumer health. An important example with critical health implications is facilitating profitable output market access to smallholders to reduce the prevalence of the invisible carcinogenic Aflatoxin fungus (Hoffmann et al. ongoing).

To make the transition to higher-value crop (HVC) production, specific market reform and information may be necessary to trigger related technology adoption. Bernard et al. (2017) find that small improvements in product market functioning, in this case third party quality certification, can trigger technology adoption among onion farmers, increasing the quality of domestic production in Senegal. However, market regulation would be needed to sustain these benefits given the shift was met with resistance from intermediary traders with market power. Further along the supply chain in retail markets in a major Chinese city, Bai (2017) introduces laser-cut labels as a less counterfeit-susceptible quality certification method for small-scale watermelon sellers. Sellers with this laser-cut branding on average provided higher quality melons (measured by sweetness) and "earned 30-40% higher sales profits on average as a result of both higher prices and higher total sales" (Bai 2017). This demonstrates demand for reliable quality signals by consumers; widely-used and counterfeit-susceptible stickers did

not result in statistically significant higher quality melons nor sales improvements. However, these individual sellers did not sustain the expensive laser branding, reverting back to baseline conditions indicating they lacked sufficient incentive to invest in the laser branding technology themselves (Bai 2017).

Revenue streams from HVCs suggest the potential for related contracts and means of production to increase rural productivity and profits. Casaburi and Reed (2017) conducted an RCT supplemented with quasi-experimental methodology in cocoa markets in Sierra Leone to show that even if information about crop quality passes credibly through the value-chain, smallholders may not benefit along their profit margin under certain contract conditions or other relationships with intermediaries (in this case pass-through was apparent through increased access to credit). Contracts or market regulation that are reliable and incentive-compatible are needed to insure smallholders against price risk while creating the right incentives for farmers to invest in the production of HVCs. Future research should investigate which types of contracting arrangements induce farmers to adopt HVCs and generate maximum surplus on both sides of the contract.

3. **Intermediaries provide interlinked services; interventions aiming to shift market relationships can produce important, unanticipated effects:** Existing intermediary relationships may be attractive to smallholders because well-informed local traders can interlink a variety of agricultural services in a single relationship. In Sierra Leone, palm oil producers were hesitant to break relationships with traders by storing harvests to reap larger benefits (Casaburi et al. 2014). In focus groups, farmers reported that they found it difficult to break existing relationships with traders (who would prefer to buy at harvest time, when prices were low). This is evidence that established relationships with traders can reduce the likelihood that producers seek alternate, even potentially more profitable, output market options.

Intermediaries can stand-in for otherwise missing financial service providers. In Kenya, dairy farmers preferred to sell to cooperatives and receive smaller, bulked payments as a form of savings rather than sell to traders and receive daily payments (Casaburi and Macchiavello 2016). In Sierra Leone, cocoa market traders build committed relationships with producers through credit provision. Cocoa quality premiums from export markets aren't passed through to producers via better prices, but credit provision increases (Casaburi and Reed 2017). Ghani and Reed (2017) also see a previously monopolistic ice manufacturer extend trade credit particularly to loyal fishermen customers in response to an increase in new ice manufacturer competition that would reduce fishermen's incentives to remain loyal to the supplier (i.e. reduced supply risk). Macchiavello and Morjaria (2015) use quasi-experimental methods to understand relational contracting in Rwanda's coffee sector, finding that increased competition among mills reduced pre-harvest service provision to farmers given anticipated reduction of post-harvest loyalties, for example increasing default risk on credit services.

The evidence demonstrates how producers' relationships with market intermediaries can involve services that should not be overlooked. These services may be provided at the expense of intermediaries, who may themselves be operating with limited profit margins (Casaburi, Reed and Dillon 2017). More research is needed to understand these dynamics as ongoing policy efforts aim to change market structures to benefit the rural poor.

Field experiments that generate rigorous evidence on the role of input and output markets on smallholders' technology adoption, productivity, and profitability have been limited to date. Consensus on the evidence base in this area seems premature, and ATAI plans to commission additional pilots and randomized evaluations to contribute to the remaining open questions reviewed in this section. Related takeaways for policy and future research are integrated in the overall conclusion below.

CONCLUSION

Productivity-enhancing technological interventions do not subsequently see widespread adoption in Sub-Saharan Africa and parts of South Asia, demonstrating that the adoption puzzle has not been "solved." But what have we learned from field experiments thus far about the binding barriers to agricultural technology adoption and how to overcome them?

Smallholder farmers in rainfed contexts face a range of different challenges to technology adoption that limit the modernization of agriculture. High transport costs due to bad infrastructure drive up the price of inputs and down the price of outputs, reducing the set of technologies that can profitably be adopted in remote locations. Variation over time (weather, prices, financial/life events) and space (soil chemistry, microclimates, distance from market hubs, etc.) influence investment decisions and resulting productivity and profits, but these factors can be difficult for smallholders to observe, manage, or predict.

Risk mitigation is key for supporting smallholders in rainfed contexts, but solving risk constraints within agriculture is difficult. Commercial index insurance targeted directly at farmers is unlikely to solve the problem given the lack of demand. Future efforts will need to test alternate approaches to insurance, whether by creating more sophisticated indexes, providing subsidized policies as a form of social protection, or selling insurance at the meso-level to financial institutions to function as a re-insurance. Comprehensive risk protection solely through improved seed variety adoption occurs rarely. Future research should focus on risk mitigation approaches that use different instruments to collectively address a range of types and severity of risk across landholders and laborers, combining the benefits of specific risk-mitigating crops, emergency loans, and other risk protective financial products where they're needed.

Formal credit markets appear too high-risk and low-return to develop in a way that reaches smallholders without supportive investments in creative, targeted product design and financial institutions. Targeting farmers' liquidity by introducing standard formal credit and savings interventions is typically met with low take-up. Farmers may already have informal credit they can access for agricultural investments when better protected from risk; this shows how risk mitigation and formal credit are interrelated and should be tackled in tandem. Experiments have identified promising ways to use information, timing, and new types of collateral to unlock credit where liquidity is constraining investment. Where credit and savings products are carefully designed to meet smallholders' needs, those who take them up change their agricultural practices, though on average it is uncommon and difficult to detect improved profits.

Behavioral economics provides an important product design lens for credit, savings, insurance, and information interventions. When designing products and services to support smallholder farmers, considering the behavioral biases that may be hampering agricultural decision-making over long time-frames characterized by uncertainty and risk can inform effective product design. Low-cost product design features like nudges, reminders, or commitment devices have been shown to support smallholders' decision-making.

Heterogeneous agro-ecological and market conditions mean that in many contexts, not all farmers have the necessary complementary factors to reap returns from a particular technology. Supply-side constraints should not be overlooked, especially in contexts where reliable access to quality, context-attuned technologies is uncertain. Heterogeneity of circumstances and limited social connections can also hamper access to and learning about new technology. Improved extension may be critically important for new technology adoption, especially when a technology is not readily understood or will have a wide range of outcomes that are context-dependent.

New information is only useful to the degree that it is both novel and profitably actionable, and business-as-usual extension is often ineffective. Falling information costs and improved communication technology provides a number of entry points for new interventions that provide novel, timely, tailored, or high-frequency information to market participants. Improved extension systems should align the incentives of public and private input agents and contact farmers. More timely, accessible, and tailored information, provided by leveraging ICT tools, and carefully selected entry points for new information and inputs can encourage the spread and inclusivity of information and related technologies.

Telecommunications are now sufficiently widespread that additional impact from price information interventions on the margin may be small. There does appear to be some efficiency created by price notification systems, however, and if their price is small this may be a welfare-enhancing intervention. Price information alone is unlikely to be enough for producers to access more profitable points of sale, although there is evidence that sharing price information can lead to the convergence of prices across markets with welfare benefits for farmers.

Small-scale producers often lack sufficient and sustained incentives to adopt productivity- or quality-enhancing technologies under current output market structures. There is scope to use technology to improve contracting and enhance the flow of information, but scaling research studies to durable institutional models is difficult. Relationships with intermediaries vary across contexts, and the nature of these relationships, in addition to the costs of doing business, affect how value chains are structured and whether and how favorable prices or other benefits pass-through to producers. There is work to be done to understand the costs of infrastructure, the competitiveness of value chain intermediaries, the potential for contract farming and other market linkage arrangements, and how value chain actors respond to market reforms such as crop-quality and pricing in supply chains.

MOVING BEYOND THE ADOPTION PUZZLE TO AGRICULTURAL TRANSFORMATION

This body of rigorous evidence provides valuable insights for those who aim to increase agricultural technology adoption among smallholder farmers. The individual randomized evaluations that make up this summary are convincing for their ability to identify causal relationships with clean internal validity. This methodological rigor makes these field experiments a useful and important tool to understand "what works" for farmers who face these particular constraints. An equally valuable role for randomized evaluations, though often overlooked or underappreciated, is their ability to identify what does not work -- allowing us to test important hypotheses and critically examine common assumptions.

The optimistic cross-cutting conclusion stemming from this rigorous body of evidence is that there is in fact potential to induce technology adoption from alleviating a specific binding constraint. When farmers are induced to adopt credit or insurance products, or when they are provided with a more saturating information environment, they respond by adopting new technologies in greater numbers. These findings highlight the

importance of prevalent logistical challenges: quite clearly, the specific mechanism by which credit, insurance, or information is delivered has significant influence on its effectiveness. The clear points outlined in the sections above offer specific suggestions of promising approaches to improve the demand and the efficacy of credit products, risk products, and extension products.

The randomized evaluations reviewed in this chapter typically focus on relaxing one or two specific constraints to adoption. While the evidence suggests that relaxing a particular constraint can lead to some additional adoption, the fraction of farmers who are induced to adopt new technologies when any of these constraints are lifted is small, and the net effects on farm profits smaller still. This suggests that generating slack in any of these particular constraints only induces a small number of farmers to adopt, perhaps because alleviating one constraint is only effective until a different constraint starts to bind. In other words, while relaxing credit, risk, or information constraints can spur technology adoption, adjusting any of these constraints in isolation seems unlikely to be transformative for the agricultural sector as a whole.

In part, this reflects the returns on available technologies: many technologies that remain un-adopted and that farmers have access to, or which farmers could easily access, may have positive but marginal returns rather than individually transformative returns. The relatively low demand for credit products suggests that many farmers do not perceive available, as-yet-unobtained technologies to have (risk-weighted) returns larger than the interest rate on these loans. In other words, as has been concluded by de Janvry (2016), singularly transformative "silver bullet" agronomic technologies do not appear to be available.

If the goal is to induce transformative change, absent the availability of inexpensive and transformative technologies, we suggest a related agenda for the frontiers of experimental research on these topics. Building on the existing, rich experimental evidence base focused on individual constraints, there is a clear need to evaluate interventions which can lift multiple constraints at once. The evidence summarized here has largely stayed away from bundled interventions with many moving parts in part due to the complexity of associated evaluation design and the challenges in interpreting behavioral mechanisms which respond to a complex product. We suggest that experimental researchers may want to focus in particular on the markets and institutions which could allow improvements from the adoption of marginal technologies to aggregate into transformative change.

A potentially valuable coordinating mechanism would be interventions in value chains: as value chains are strengthened and distributed, input quality becomes more reliable, presumably information costs would decrease as would the returns to financial intermediation. Market-level and infrastructure-level constraints may be the most binding to transformative effects, yet are the most expensive to alleviate and have thus far been difficult to study in the context of RCTs. However, a rise in the use of RCTs and related measurement techniques has fortunately broadened the scope of questions that have been creatively tackled while remaining true to the rigor of the experimental technique. Rigorous evaluations that can illuminate the functioning of value chains are ripe for further innovation, and studies currently in progress and forthcoming from ATAI may illustrate a path forward.

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