Market inefficiencies and the adoption of agricultural technologies in developing countries[1]

Agricultural Technology Adoption Initiative
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Introduction

Throughout the world, and particularly in South Asia and sub-Saharan Africa, many of the poorest people are farmers. Nearly 75 percent of those subsisting on $1 a day live in rural areas, and it is estimated that the majority of the poor will remain rural until 2040 (Ravallion et al. 2007). At the same time, agriculture is a major source of income and employment in these regions: it accounts for 34 percent of Gross Domestic Product (GDP) and 64 percent of the labor force in sub-Saharan Africa. Poverty alleviation is therefore directly linked to agriculture. Whether in the form of new crops, improved breeds of animal, or changes in agricultural practices and crop choice, technology has the potential to sharply increase yields, reduce spoilage and risk, and improve the nutritional quality of food.

While the Green Revolution benefited many farmers, the adoption of promising agricultural technologies has been far from ubiquitous, and has remained particularly low among the poor—leading to concerns that the Green Revolution may have increased both intra-and inter-regional inequalities in South Asia (Freebairn 1995). In sub-Saharan Africa, adoption of new technologies has lagged behind that of Asia. For example, by 2000, adoption of modern varieties of maize was estimated to be 17 percent of total area harvested in sub-Saharan Africa compared to 90 percent in East and South East Asia and the Pacific, and 57 percent in Latin America and the Caribbean (Gollin et al. 2005). Increased technology adoption—broadly defined to include adoption of improved agricultural practices, crop varieties, inputs, and associated products such as crop insurance—has the potential to contribute to economic growth and poverty alleviation amongst the poor, particularly in sub-Saharan Africa.

Historical examples suggest that adoption of beneficial technologies does occur in sub-Saharan Africa when conditions are right. Taking a longer-run perspective reveals that many current staples in sub-Saharan Africa arrived relatively recently (in the last 600 years) from the New World, including maize, cassava, and sweet potato. Many of the region's cash crops are also transplants that have been adopted and successfully diffused, driven largely by market forces. This historical evidence suggests that over a sufficient time frame, "good" technologies can succeed even without external efforts to promote them.[3] This begs the question of whether low adoption rates of technologies that are touted as profitable by their promoters are due to poor circumstances or to poor technologies.[4] Poor circumstances, created by poorly functioning economic markets in rural areas, lower the profits that a farmer receives from technology adoption. Examples of these market imperfections include "missing markets" for risk, credit, or land (i.e. a lack of formal insurance providers, financial institutions or the ability to buy, sell,

[3] Thanks to Doug Gollin and Marcel Fafchamps for highlighting these historical precedents.

[4] It has been further pointed out that current knowledge of adoption rates is poor. Little is known about what is grown and where, with most adoption estimates coming from databases kept by the Food and Agriculture Organization (FAO), which rests on weak microfoundations in many cases.

own, or reliably hold onto one's land). At the same time, in the absence of any market inefficiencies, unprofitable technologies will, rightly, go unadopted.

Considerable agro-ecological heterogeneity across locations in Sub-Saharan Africa means that technologies vary across relatively small areas. Agro-ecological heterogeneity is a consequence of the high dependence on rainfed agriculture and microclimates that require specific farming practices. Technologies may be disproportionately suited to the growing conditions faced by the wealthiest farmers, resulting in selective unavailability of appropriate technologies for other farmer types. Adoption will not occur where technologies are unavailable, yet selective availability is largely a supply side, technology development challenge less suited to targeted interventions to encourage take up.

The approach taken by the Agricultural Technology Adoption Initiative (ATAI) assumes that beneficial technologies do exist and that successful strategies for addressing the constraints on their adoption will improve welfare. ATAI therefore intends to target technologies that are profitable in a world with perfectly efficient markets, but that are currently underadopted, which suggests some market failure. For example, many technologies might enjoy higher adoption rates if credit markets offered low-interest loans or if property rights were secure. While there is pressing need for more systematic evaluations of the true profitability of many "good" technologies, the field trials needed to determine true profitability are costly and not the expertise of ATAI researchers. As a simple rule of thumb, if technologies are adopted in some places by some farmers, it is likely that improving market efficiency or providing farmers with strategies to overcome existing inefficiencies will increase adoption. This targeting of technologies allows ATAI to focus on identifying and testing approaches for addressing underlying constraints on the broader adoption of beneficial technologies. Proposals for ATAI-sponsored research will be asked to identify the current extent of adoption of the targeted technology and discuss its potential for expansion.

This literature review summarizes selected research on market inefficiencies that constrain agricultural technology adoption and how these inefficiencies can be overcome. In analyzing this question, the review draws upon relevant findings from agricultural and non-agricultural studies in economics and related disciplines. The literature review is far from exhaustive, though it offers some structure and background on research relevant to the challenge of agricultural technology adoption. The objective is twofold: to provide information about strategies to overcome adoption constraints to the promoters of agricultural technologies and to identify gaps in the literature which ATAI researchers will seek to fill as the initiative progresses. In the initial stages—while there are many gaps to be filled—the document's primary use will be to guide ATAI researchers in focusing on the most important gaps in knowledge. This document therefore highlights open research questions under each of the market imperfections considered. As the work under ATAI progresses, the document will be updated to reflect the latest research on agricultural technology adoption strategies. We begin with further discussion of the true profitability of agricultural technologies, followed by a preview of the seven market inefficiencies that we highlight as causes of low adoption of beneficial technologies. We then examine these seven market imperfections in detail, covering both what is known about associated adoption constraints and also what is known about ways to overcome these constraints. Well-identified empirical micro-economic studies are far more prevalent for some of the constraints than for others. For example, numerous studies explore information and credit market inefficiencies and test or evaluate interventions designed to overcome them. For externalities or land market failures, far less rigorous evidence is available. Some of this variability is likely due to the feasibility of random or quasi-random micro-variation in the variable of interest.

Meeting the expected profitability condition

An agricultural technology may dramatically increase yields or agricultural output but that does not necessarily mean that it should be adopted. For example, some crops may have higher yields but also may be more sensitive to drought. Making these technologies profitable requires large investments in irrigation infrastructure, which, in some places, may be very costly. Once the added costs of infrastructure development are factored in, the comparison of costs and benefits for the new crop may not make it worthwhile for either society or for the individual. The individual farmer would benefit more from receiving the money directly because the costs of the technology are greater than the benefits. When calculating whether or not a technology is worthwhile, it is therefore important to take into consideration the labor and capital investments that are necessary to enable adoption of the technology.

In the irrigation example, the labor and capital costs of infrastructure development are real costs. In general, if the real costs are less than the total value created by higher adoption rates, then the investment is worthwhile. However, market inefficiencies may add additional “costs” that make the project appear unprofitable. For example, investments with high initial fixed costs, such as irrigation development, may present difficulties for securing a loan if credit markets are weak. The initial investor may not be able to recover these fixed costs from future users if contracting is difficult. Similarly, at the household level, worthwhile investments may be bypassed if market inefficiencies lower the profits that the farmer receives from adoption. In addition to market imperfections, profitability is also affected by factors that range from individual tastes and preferences to macroeconomic policy.

We define a good technology as one that is profitable in an ideal world without market inefficiencies or other adoption constraints. In that world, adoption perfectly reveals whether a technology creates benefits greater than its costs. However, moving away from the ideal, the individual adoption decision reflects all of the distortions created by market failures and market inefficiencies. Consequently, an agricultural technology that is profitable to one farmer may not be profitable to her neighbor because of differences in credit access or because of household-specific labor constraints. Assessments of the profitability of existing agricultural technologies often stop at the demonstration plot, and may not include all inputs such as household labor (Foster and Rosenzweig 2010). Thus, in many cases, we lack even the information needed to determine where to best invest resources aimed at improving farmer welfare through technology adoption.

Profitability varies with weather, price, and other shocks. The expected profitability of a technology considers the full range of these variable conditions. Expected profitability also varies spatially, with microclimates or distance from urban centers. Individual or household preferences will also affect the perceived benefits from adoption, which may vary within the household. For example, productivity increases due to the introduction of high-yield varieties have been successful in ecologically favorable areas but have often bypassed smallholders on marginal land (Almekinders and Hardon 2006). While well off farmers are able to correct unfavorable micro-environments through inputs such as irrigation and fertilizer, poorer farmers are not. The profitability of highly sensitive technologies will be affected by the characteristics of the individual adopter, the microclimate and other variable factors (Evenson and Westphal 1995). The fact that a technology is profitable in some circumstances does not mean that it should be adopted by all farmers. For example, rates of return to improved crop varieties are often high on experimental plots but may not be uniformly positive across farmers or plots (Suri 2009). Official sources of information are often developed in response to conditions on test plots, and may therefore deliver instructions for cultivation that are inappropriate for some farmers (Duflo et al. 2008).

Individual preferences around product attributes, including taste and cultivation practices, will affect how profitability is perceived by the household. This is particularly true of production for home consumption. Farmer perceptions of technology attributes, such as ease of preparation and cooking, have been linked directly to adoption outcomes (Adesina and Akinwumi 1993). Technologies imported from other regions may have different flavors and textures than local substitutes and may not be adopted even if they increase yields and income (e.g. Gafsi and Roe 1979). Evidence shows that low income consumers in the developing world are willing to trade off substantial caloric intake for preferred foods (Atkin 2012). Preferences, and therefore perceived profitability, are also shaped by social context, and norms around food and agriculture may guide aggregate adoption patterns (Bardhan and Udry 1999). Social norms are relevant for technologies where individual adoption decisions generate costs and benefits from both the profitability of the technology and the possibility of social sanction (e.g. Munshi and Myaux 2006).[5]

Though a technology may be profitable for a household as a whole, within the household, costs and benefits of adoption may not be equally distributed. Evidence from models of intra-household decision making suggests that the household is not always the correct unit of analysis for understanding technology adoption. Constraints may differ among individuals within the household (e.g. Duflo and Udry 2004). In particular, gender affects access to labor, land, and other important inputs

[5] Munshi and Myaux (2006) apply a social learning model with social norms to fertility decisions, where the probability of interacting with an adopter of the new technology affects the likelihood that the whole community will go toward a “modern” equilibrium. In their model, health workers are a source of exogenous information, similar to the role that the extension worker has in the agricultural models.

for production, and may also affect preferences around production processes and outputs (Doss 2001). Gender roles and dynamics are likely to be locally specific, so approaches that benefit women in one setting may have no effect in other settings. The distributional consequences of new technologies are therefore difficult to predict. Once women are able to overcome their disproportionately high resource constraints, they may be at least as likely to adopt agricultural technologies that are appropriate for them (Kumar 1994).

The macroeconomic environment also directly and indirectly affects agricultural prices, and therefore the profitability of new technologies for potential adopters. In many countries where agricultural growth is most needed, policies that favor the urban and industrial sectors affect agricultural input and output prices, potentially making adoption of agricultural technologies less profitable to rural households (Krueger et al. 1988). Government policies that directly distort prices include tariffs, input and credit subsidies, price controls, quantity restrictions, and government expenditures. Indirect distortions on agricultural profitability and prices include industrial protection, exchange rates and interest rates, and other fiscal and monetary policies (Schiff and Valdés 2002). To the extent that profitability of agricultural technologies is determined by government macroeconomic and sectoral policies, microeconomic interventions may target unprofitable technologies or may fail to generate adoption of profitable technologies. While microeconomic research focused on overcoming barriers to agricultural technology adoption are unlikely to remedy these policies, they must be cognizant of the resulting market distortions.

Conceptual framework: Market inefficiencies and technology adoption

The conceptual framework identifies and describes a series of market inefficiencies that constrain the adoption of beneficial agricultural technologies.[6] By organizing constraints on technology adoption around market failures, the framework helps organize potential strategies for increasing adoption by making markets more efficient or by providing farmers with strategies to overcome existing inefficiencies. The focus is on available (existing) technologies that meet the expected profitability condition, as described above. We identify 7 market imperfections that constrain agricultural technology adoption. The relative importance of these inefficiencies will vary across time, space and target population.

The market inefficiencies identified in the conceptual framework do not neatly splice considerations such as the spatial distribution of adoption constraints, nor do the market imperfections exist in isolation. In many cases, the presence of one market failure may be exacerbated by the presence of others. Little is known, however, about the relative efficacy of interventions to relax adoption constraints one-by-one versus interventions that relax a suite of constraints simultaneously. While adoption may not require that all market imperfections are overcome

[6] This typology of constraints to adoption offers an alternative to that used by Kelly et al. (2003), which differentiates financial profitability of a technology from its economic profitability. Other recent typologies of agricultural technology adoption are found in Foster and Rozensweig (2010) and Udry (2010).

simultaneously, much more needs to be understood about how the barriers to adoption relate to one another and whether some consistently matter more than others. Targeting a single constraint while ignoring the others may be unsuccessful, but at the same time, attempts to address all seven simultaneously may not be cost-effective or necessary. Where multiple impediments to adoption intersect or where a solution to one market inefficiency also offers a solution to other adoption constraints, it is mentioned in the text. To the extent possible, research under ATAI will go beyond addressing single constraints to investigate whether it is necessary to work on multiple market inefficiencies at once or whether progress can be made on single constraints.

Externalities – Some technologies create spillovers that affect others. If farmer decisions ignore these spillovers, then technologies that create benefits for others may not be adopted, while technologies that impose costs on others may be adopted too widely.
Input and output market inefficiencies – Problems with infrastructure and with supply chains, compounded by weak contracting environments, make it more costly for farmers to access input and output markets and access the benefits from technology adoption.
Land market inefficiencies – In settings where land tenure is weak and property rights insecure, farmers may not have an incentive to invest in beneficial technologies.
Labor market inefficiencies – New technologies need different types and timing of labor input. Restrictions on labor mobility and high costs in the labor market will interfere with adoption opportunities.
Credit market inefficiencies – Many farmers have difficulty accessing credit and face high interest rates, which prevents investment in profitable technologies. Financial decisions may be difficult for farmers without high levels of financial literacy.
Risk market inefficiencies – Technologies that carry a small risk of a loss may not be worth large expected gains if risks cannot be offset. Psychological issues around risky decisions further lower levels of adoption.
Informational inefficiencies – If an individual does not know that a technology exists, does not know about its benefits or does not know how to use it effectively, then the technology will not be adopted.

Some types of market imperfections cannot be resolved by focusing on the individual farmer. In these cases, interventions must work with groups of farmers, with markets, and with institutional arrangements that shape the costs and benefits of individual decisions. Efforts to address these underlying problems can seek to improve the whole market, or can target individuals' capacity to adopt agricultural technologies in the face of market inefficiencies. For example, alternatives to standard forms of collateral (e.g. future profits instead of current property) may improve access to credit for the very poor without necessarily addressing the functioning of the credit market overall. In other cases, the relevant level for intervention is clearly the supply chain or market. Upstream and downstream marketing appears key for the development of an export oriented agricultural sector. For example, cotton production is most successful in countries such as Zambia when it is combined with the distribution of inputs on credit and with in-country processing. The success of flower export markets in Kenya and Ethiopia is dependent on transportation technology and reliable airlines.[7] These examples all manage to overcome—for some farmers—the adoption constraints imposed by input and output market imperfections and poorly functioning credit markets.

However, even when market inefficiencies are addressed, profitable and accessible technologies may go unadopted for behavioral reasons, such as self-control problems or aversion to losses (e.g. Duflo, Kremer and Robinson 2010). Behavioral economics offers an intriguing set of theories on how to help people overcome these heuristics and biases. Further application of these ideas to the promotion of agricultural technologies may help increase adoption. Behavioral or psychological barriers to adoption may exacerbate existing market failures or inefficiencies, but they may also hinder adoption even in perfectly functioning markets. Within the set of market failures discussed in this literature review, behavioral adoption barriers are discussed where they are most likely to interact with or result from one or more of the market failures. Other factors, such as gender, are cross-cutting and affect the strategies for and the distributional consequences of overcoming each of the adoption constraints. Approaches to improving gender equity in agriculture may therefore have the cross-cutting impact of lowering all barriers for women farmers.

In the following sections, each of the seven market imperfections is assessed for what is known about the circumstances under which it arises, including the types of farmers, technologies, and contexts most affected; for what is known about how to overcome the challenge; and what is not known or priorities for research. Rural and women smallholders are given particular attention as the types of farmers targeted by ATAI, with an emphasis on subgroups that include the landless and the less educated. Scalability of a technology is probably the most important determinant of overall impact, so approaches with the potential to benefit the very poor as well as those on the edge of poverty may lead to greatest overall take-up.

Not all market inefficiencies pertain to all types of agricultural technology. By focusing on constraints rather than specific technologies, the goal is to identify strategies to relax constraints that have the potential to be useful for promoting more than one technology. Six types of technologies are identified by the benefits they offer. Throughout the paper, these types of technologies are referred to, and the table below provides an illustration of some specific technology examples currently studied by ATAI projects.

Technology type	Specific examples
Higher yields	Improved varieties Micro-irrigation
Lower risk	Drought-resistant crops Weather insurance
Better quality	Certification schemes Storage technologies
Lower costs	Animal-driven plowing Nitrogen-fixing crops
Reduce externalities	Reduced till agriculture Terracing

[7] Thanks to Marcel Fafchamps for pointing out these examples.

1. Externality related inefficiencies

For some agricultural technologies, not all of the benefits accrue to the individual who adopts them. For example, practices that reduce erosion, conserve water, or control pests may benefit the wider community—not just the practicing individual farmer (Millennium Ecosystem Assessment 2005). Similarly, the first farmers to adopt a new technology in an area may generate positive externalities for other farmers in the form of information about how to use the technology (Besley and Case 1993; Conley and Udry 2001). In all of these cases, there will be less investment in a new technology than is optimal, as long as individual farmers are not rewarded for the benefits that they generate for others (Foster and Rozensweig 1995; Waibel and Zilberman 2007). Prices that do not reflect the costs and benefits that adoption generates for the rest of society lower expected profits relative to what they would be were all externalities internalized. In particular, technologies that improve environmental quality without increasing agricultural output will tend not to be adopted, even though they may be beneficial to society as a whole.

The classic solutions to externalities problems involve correcting prices through taxes or subsidies, or establishing quantity limits such as quotas (which also work by changing prices) so that prices reflect social costs and benefits. Though a number of development interventions use price incentives to correct for externalities, little rigorous research has been done. Challenges to internalizing externalities from adoption include the costs of monitoring, a problem that characterizes several of the barriers to adoption, such as contracting and finance. Thus, approaches to reducing the cost of monitoring agricultural decisions, some of which have been subject to extensive research, are likely to simultaneously lower a number of barriers. Externality barriers to agricultural technology adoption are also related to informational inefficiencies (Section 7), to the extent that early adopters generate valuable information for others, as well as to a lack of property rights (Section 3).

1.1 What is known about externality related inefficiencies and technology adoption?

Early adopters of a technology provide information for others about the benefits from and correct use of a technology, and disproportionately bear costs of the learning process. When adoption rates are low, adding one more adopter in a network increases the likelihood of adoption by others (Bandiera and Rasul 2006). However, when adoption rates are high, an additional adopter in a network makes adoption less likely. This indicates that the incentive to strategically delay adoption and free ride on the knowledge accumulated by others becomes stronger when information is more plentiful. Informational externalities resulting in delayed adoption are most likely in settings where learning from other farmers dominates other sources of information; for example, areas without adequate agricultural extension coverage, or where farmers and plots are relatively similar, decreasing the importance of a farmer's own experience relative to the experience of others. Technologies that carry greater value for strategic delays, such as investments that are difficult to undo or that cannot be adopted incrementally, are more likely to diffuse slowly because of the information externalities associated with adoption.

Information externalities are not the only reason that farmers strategically delay adoption. Any type of positive spillover from technology adoption within a geographic area or social network creates an incentive to postpone adoption and free ride on the benefits provided by others. Strategic delays have also been observed in the adoption of health products that generate immunity benefits for others (Kremer and Miguel 2007). Similar immunity externalities may occur with pest-resistant agricultural technologies, where a landholder's risk of pest damage is decreased if his or her neighbor adopts a pest-resistant crop strain, though this type of immunity externality has not been documented.

Natural resources, such as air and water, also act as a conduit for externalities from agriculture, and create both local and global health and productivity effects. For example, 1.4 billion people live in river basins where extraction rates exceed replenishment (UNDP 2006), yet because the costs of depletion accumulate downstream, private action to reduce water use is not undertaken. In some policy environments, technology subsidies contribute to resource-depleting activities, such as electricity subsidies that lead to overextraction of groundwater, or chemical fertilizer subsidies that generate downstream pollution (World Bank 2008). On the other hand, subsidies for agricultural practices that generate positive externalities are gaining popularity.

The market failures around externalities are due largely to the difficulty establishing property rights around information or environmental spillovers, which prevents the producer of a positive externality from charging beneficiaries for use. Without ownership of the externality, technologies that improve environmental quality without increasing agricultural output will tend not to be adopted even though they may be beneficial to society as a whole. Activities that create environmental externalities may also affect the value of land use on neighboring plots. For example, in Costa Rica, Robalino and Pfaff (2012) find that individuals are more likely to deforest when their neighbors deforest. The authors are not able to isolate the drivers behind these spillovers, which could include strategic complements in either conservation (the value of my forest is higher when my neighbors also have forest) or deforestation (the cost of clearing is lower when my neighbors also clear). Concerns about environmental impacts sometimes directly conflict with short-run poverty alleviation, such as for water extraction technologies that simultaneously increase income for the adopter and lead to depletion of the resource for others (e.g. Kerr 2002).

New agricultural technologies have both been blamed as the cause of increased degradation and lauded as a potential solution (Lichtenberg 2002). Approaches that leverage ecological factors specific to the local environment—the "agroecological approach" —typically require few purchased inputs and can reduce the environmental impact of agriculture by utilizing natural pest resistance. Intercropping with nitrogen-fixing trees, for example, may reduce erosion and the need for chemical fertilizers and can also generate wood fuel for cooking, though the benefits relative to input costs have not been rigorously documented. Relatively high rates of zero tillage adoption are probably due to the multitude of benefits it offers to the landholder (and to others): savings in fuel and machinery costs, improved soil moisture, structure and hydrology, improved timing of double-cropped systems, reduced sedimentation, improved soil and above-ground biodiversity, and reduced CO_2 emissions. However, these approaches are often complex, demand labor and knowledge to implement correctly, and may be more sensitive to small ecological variations across plots (Lee 2005; World Bank 2008).

Many natural resource-related externalities require collective action among resource users to move from a situation of over-extraction to one of sustainable management. Groundwater depletion, for example, is a common property resource where each individual's extraction choice is increasing in the extraction of his neighbor. As multiple users of a groundwater source shift toward more productive forms of agriculture, the payoffs associated with water extraction increase more quickly than the costs, since benefits are felt privately while costs are shared among all groundwater users. In India, large farms use surprisingly shallow wells. This suggests that their size forces them to internalize some of the externalities associated with overextraction, because much of the effect of groundwater depletion is felt by the same landholder (Foster and Rosenzweig 2008). Incentives for overuse exist for other shared natural resources. The likelihood of collective action to resolve natural resource-related externalities tends to depend on the costs of cooperation, which vary with spatial factors, existing norms, and heterogeneities among users (Pender and Scherr 2002; Godquin and Quisumbing 2008).

Environmental and health externalities from agriculture are likely to disproportionately affect the poor, who are most dependent on natural resources (WRI 2005) and tend to live in fragile ecosystems (Hassan et al. 2005). At the same time, the poor's dependence on natural resources may increase the environmental degradation resulting from marginalization as households are forced to turn to natural ecosystems for their livelihoods (Bardhan and Udry 1999). On the flip side, recent evidence from Mexico shows that poverty alleviation may actually increase deforestation due to shifts toward more land-intensive consumption patterns (Alix-Garcia et al. 2011). It has also been argued that women bear disproportionate costs of environmental degradation since they are the primary users of natural resources or common property resources (Schutz 2001). For example, as deforestation increases, women may be forced to invest more time in fuelwood gathering.

A looming challenge for agricultural productivity stems from market failures surrounding externalities on a global scale. The potential impacts of climate change on agricultural production are likely to be negative throughout sub-Saharan Africa and most of South Asia, yet the magnitude and distribution of the impacts are highly uncertain. For example, Burke et al. (2011) estimate a decline in production between 14 to 86 percent (with a point estimate of 40 percent) in sub-Saharan Africa. In spite of the potential severity of climate impacts on agriculture, relatively little rigorous work on adaptation has been carried out, though related research on adoption of drought-resistant crops can inform strategies for adapting to climate change.

Contexts characterized by many diffuse sources of negative environmental externalities present particular challenges to addressing externalities because of the difficulty in tracing an outcome, such as water pollution, to its source (Hahn and

Stavins 1992). Nonlinearities in the environmental impact of agricultural practices (such as deforestation patterns that lead to species extinction at an increasing rate, or water quality problems that affect human health only above a certain threshold) are also hard to regulate. This is due to the difficulty in setting policy targets that capture these nonlinearities (Arrow et al. 2000). Difficult-to-observe environmental externalities, such as biodiversity, may be less likely to spur technology adoption because the consequences of investment are hard to monitor and reward.

1.2 What is known about how to overcome externalities?

New institutional arrangements that attempt to align individual farmers' incentives in the face of externalities are being developed. These frequently take the textbook approach of changing the prices associated with externality generating agricultural practices, offering penalties for those that generate negative externalities and rewards for those that generate positive externalities. Through these price adjustments, the effects on others are felt by the individual adopter. Incentives for early adopters may also be provided through informal mechanisms at the community level, which can eliminate the incentive to free ride on the benefits provided by others (Bardhan and Udry 1999). However, little empirical evidence is available on existing informal mechanisms or on approaches to formalizing and scaling up. In a study of the long-run adoption patterns of insecticide-treated bednets in Kenya, Dupas (2013) provides some evidence that financial subsidies for early adopters encourages greater adoption by neighbors in future periods. These findings provide a justification for subsidies in light of the information spillovers generated by early adopters. In agriculture, other types of rewards for early adopters—for example, tying an incentive to the number of other adopters in a village—have been suggested, but not tested.

Approaches to addressing externalities from agriculture that do not require the degree of monitoring and enforcement needed for regulatory approaches may be particularly suited to developing country settings (Lichtenberg 2002). For example, where farmer actions are difficult to observe, implementation of "best practices" subsidies is more challenging. Input-based approaches are more feasible, because the former can be effectively applied through the input market without attention to subsequent use. Experience with incentive-based approaches in developing countries remains limited, but developed country policy evaluations point out potential pitfalls (e.g. Wu 2000). A large theoretical literature on agricultural policy for pollution control investigates policy design, but often fails to translate policy design into farm-level technology adoption decisions.

Payment for environmental services, such as the return of carbon credit revenues to communities that generate them, uses positive price incentives to address externalities. In the case of carbon credits, there are difficulties with measurement of creditable activities and with additionality under existing programs that continue to hinder the approach.[8] For example, Costa Rica's pioneering program of payments to reduce deforestation has been shown to have little effect on actual deforestation rates because the majority of payments go to landholders unlikely to deforest in the absence of the program (Pfaff et al. 2006). In addition, transaction costs are high under many of these programs and are borne mostly by publicly funded intermediaries. Uncertainty in the relationship between actions taken to reduce environmental externalities and the resulting environmental benefits (for example, restrictions on cattle grazing that have uncertain effects on water quality) also makes solutions more difficult to implement (Weitzman 1974). In practice, this uncertainty generates a large risk premium that must be shared between those paying for environmental services and those providing them, decreasing potential gains from trade.

In spite of these obstacles, successful examples of payments for environmental services including biodiversity, carbon, and water do exist (Tipper 2002; Pagiola et al. 2008). Where landholders are rewarded for the provision of positive environmental services, the relationship between land quality and environmental service provision will determine whether such interventions are also good for poverty alleviation. In many situations, higher quality agricultural land also provides more environmental services, and as a result, involving poorer individuals in these programs may increase costs (Zilberman et al. 2008). Further research on approaches to lowering transaction costs and improving measuring and monitoring will make payments for environmental services more viable.

For resource management issues that require collective action to help reduce free riding and internalize externalities, giving user groups control over management shows mixed results. Some authors suggest that water users associations have often created better environmental outcomes than centralized management, but their performance on efficiency and productivity is mixed (World Bank 2006). Devolving responsibility of water resource management to local communities has generated negative impacts, leading to a substantial decline in water management, particularly in communities with more ethnic diversity (Miguel and Gugerty 2005). This suggests that one of the mechanisms through which devolution works is social sanctions that users can leverage to enforce agreements.

Of the natural resources important for agriculture, groundwater resources are among the most crucial, but also highly prone to externality related reasons for mis-management. The marginal extraction costs of one farmer are shared among other users, resulting in little individual incentive for conservation. Sekhri (2011) studies the effect of public groundwater provision on depletion of the resource. She finds that, in the presence of high fixed costs of private provision, public provision can – counterintuitively – lead to greater conservation of the shared resources, because public wells result in a marginal price on consumption. In a follow up paper, Sekhri (2013) uses the same discontinuity in water extraction costs to demonstrate

[8] Additionality measures the environmental benefits under the program against a counterfactual of no program. Poor additionality, leakage, and new entrants all undermine the benefits of environmental policies and extend to payments for environmental services projects (Jack et al. 2008).

the groundwater shortages are associated with 10-12 percent more poverty and higher levels of within-village conflict.

Many have argued that women may be in a better position to manage the local public goods, such as water resources, for which they are the primary users (Pandolfelli et al. 2007). Research on social forestry suggests that greater involvement of women is associated with better resource management (Agrawal et al. 2006), though studies of existing arrangements cannot address the endogeneity of greater female participation in local institutions. Rigorous evidence to support a causal claim of gender differences in natural resource management is scarce, however, and interventions aimed at encouraging women's participation in resource management organizations have not been found to improve outcomes (Leino 2008).

Case study evidence provides many examples of the emergence of self-governing institutions for collective action and natural resource management. These case studies suggest that solutions are less likely to evolve when the status of the natural resource is difficult to observe, when boundaries are hard to define, when substitutes for the resource are available, when the costs of depletion are disproportionately felt by the marginalized, or where levels of social capital are low (Ostrom 2002). In Mexico, where heterogeneities in land holding sizes are greatest, coordination around surface water management suffers (Bardhan and Dayton-Johnson 2007), perhaps because of the imbalance in resource needs and bargaining power between large and small landholders. While group composition and size are likely to be important factors in determining collective action outcomes, they may be less important than supporting institutions such as property rights and social capital (Poteete and Ostrom 2004; Mwangi and Markelova 2009). The existing case study literature highlights the importance of social norms for successful governance of natural resources, and point to common characteristics of successful management institutions: clear rules about use rights and boundaries, effective monitoring, graduated sanctions, and conflict resolution mechanisms (Ostrom 2002; Mwangi and Markelova 2009; Agrawal and Ostrom 2001). Lowering monitoring costs may therefore help reduce environmental externalities and improve natural resource management through collective action, as well as helping to address several other market inefficiencies (credit market failures, for example). Informal mechanisms that may be useful for limiting free-riding behavior include shaming, direct communication, and more participatory decision making within the community (Ostrom et al. 1992; Ostrom 2005).

Behavioral economics clearly shows that individuals may also be motivated by factors other than profit maximization, which is particularly relevant for actions that generate externalities and affect others. Other-regarding preferences and other behavioral motivations behind altruistic behavior may offer insights for the circumstances under which individuals are most likely to adopt technologies that generate positive externalities. Theories to explain other-regarding behavior include the warm glow from altruistic decisions (e.g. Andreoni 1990), fairness or reciprocity (e.g. Fehr and Schmidt 1999), reputational or dynamic considerations (e.g. Bénabou and Tirole 2003), and social norms (e.g. Bernhard et al. 2006).

Whether the findings on pro-social behavior in other contexts can be leveraged to address externalities from agricultural technology adoption remains to be tested.

ATAI researchers are exploring approaches to overcoming the adoption challenges presented by externalities. In Bolivia, Ashraf and Jack will evaluate the effectiveness of incentives to encourage the adoption of environmentally friendly agricultural practices. This project represents one of the first attempts to rigorously evaluate payments for environmental services as an approach to encourage technology adoption.

2. Input and output market inefficiencies

Poorly functioning input and output markets erode the profitability of a technology to the farmer. In many places, a lack of infrastructure drives a wedge between the prices that farmers receive for their output and the market price, lowering the benefits from technology adoption. Where infrastructure is weak, local prices are driven by local supply, which may undermine farmers' incentives to maximize output if higher output leads to lower prices. But investment in infrastructure is a public good, which results in underinvestment since those making the investment will not capture all the benefits (Jimenez 1995). Individual farmers' lack of market power, in combination with the lack of competition among input suppliers and among output intermediaries, leads to capture of much of the profit from improved technologies by market actors other than the farmer. This can lower technology adoption. By raising the fixed cost of distribution, poor infrastructure increases the market power of intermediaries. The result is a vicious cycle with low take-up, resulting in few traders with market power, which lowers profits for farmers and further depresses take-up. Weak contracting environments exacerbate many of the constraints imposed by input and output market inefficiencies by making it difficult to enforce superior arrangement.

The need to interrupt this cycle provides a rationale for targeted subsidies that can generate the initial volume required to set up distribution networks and lower costs, while ensuring that those who receive the subsidy would not have otherwise taken up the product. Farmers associations and cooperatives may offer solutions to lowering the transaction costs associated with smallholder inclusion in markets (Reardon and Timmer 2007). Approaches to overcoming adoption constraints associated with input and output market inefficiencies must further engage the private sector as a reliable source of inputs and a provider of output markets. Further research is needed on strategies for addressing inefficiencies, including contracting approaches that work even when formal enforcement mechanisms are weak, reductions in monitoring costs, and insights from behavioral economics to stimulate demand. For example, behavioral economics research has shown that default options can play an important role in coordinating behavior (Choi et al. 2003) yet, to date, no effort has been made to extend this powerful finding to agricultural technology. Inefficient input and output markets increase the risk associated with technology adoption (Section 6) and exacerbate credit market failures (Section 5).

2.1 What is known about input and output market inefficiencies and technology adoption?

Multiple studies cite unreliable supply, high prices of fertilizer, and other inputs as primary barriers to adoption. Farmers who would benefit from adoption of agricultural technologies may be unable to access or to pay for the technology due to inadequate infrastructure, missing supply chains, or unprofitably high prices.

Infrastructure plays a key role in facilitating technology adoption and investment, but much of the infrastructure necessary for functioning markets is associated with high fixed costs, broad geographic coverage, and difficulties with excluding nonpaying users. Consequently, infrastructure providers find it difficult to recover the full costs of investment and most infrastructure projects are left to public provision (Jimenez 1995). Landlocked countries in particular face enormous transaction costs associated with import and export of agriculture related products. Transportation can account for half of the cost of agricultural output marketing, which is a large fraction of the value of the product. In rural areas, poor transportation infrastructure results in local markets that depend on local demand and supply (Platteau 1996). Technologies that increase production may not translate into higher profits if higher supply lowers prices. To the extent that farmers (or groups of farmers) anticipate these price responses, they have less incentive to increase outputs. As a result, many contexts that are otherwise favorable for adoption of productivity enhancing technologies are burdened by geographically driven transaction costs that make adoption unprofitable. For example, technology adoption varies with geographic distance from urban centers, suggesting that market access and transportation costs affect returns to technologies, though these effects can also be explained through labor market channels as discussed in Section 4 (Fafchamps and Shilpi 2003).

Transport and other infrastructure challenges tend to reduce competition among input suppliers and among middlemen, which potentially allow them to charge higher input prices and pay lower prices for outputs. This is because individual farmers have little choice but to accept the offered price. Evidence on the role of information as a barrier to better functioning input and output markets, and the role of traders or middlemen in resolving these frictions, is mixed. Mitra, Mookherjee, Torero and Visaria (2013) study the importance of information asymmetries in affecting the gap between farm-gate and market prices. If middlemen have better information about market prices, then they can extract information rents from the farmers. The researchers experimentally vary the information about market prices available to farmers and find no effect on middleman margins, though changes in prices ex post move in the direction of the wholesale market price, suggesting an increase in ex ante earnings volatility. These results are inconsistent with traders smoothing price risk for farmers.

Cross-country evidence on the effect of infrastructure on agricultural productivity shows a positive relationship between productivity and the development of roads and irrigation (Binswanger 1989). Better transportation is associated with diffusion of technology, better use of inputs and better prices (Ahmed and Hossain 1990). However, recent World Bank evaluations show that road development does not single-handedly overcome all adoption barriers. Effects are sometimes heterogeneous across income groups, with better-off households benefitting more (Jacoby 2002; Lokshin and Yemtsov 2005). Other evidence from Bangladesh uses a difference-in-differences framework to evaluate the effect of rural road improvements on the adoption of high yielding varieties in Bangladesh (Ali 2011). Results show an increase in acreage devoted to HYV but no corresponding decrease in acreage under local varieties. Other types of infrastructure development also appear to benefit agricultural productivity. For example, evaluations of electrification show large benefits, particularly on agricultural GDP (Lipscomb et al. 2009) and farm production (Khandker et al. 2009).

Some within-country evidence on the relationship between geography and agricultural input and output use and prices, with the existing evidence that search costs underlie observed market outcomes. Treb Allen uses a structural model of trade and information frictions to estimate the share of local trading that can be attributed to transport costs and information frictions, with the latter standing in for all non-transport frictions. The model is estimated using regional agricultural trade data from the Philippines and finds that a substantial amount of what determines trading locations can be explained by informational frictions. Casaburi, Glennerster and Suri (2012) also investigate the effect of rural transportation costs on price dispersion in agricultural markets, using a regression discontinuity for road improvement in Sierra Leone. They find evidence consistent with a model of search costs, which predicts that crop prices fall with road improvements and more so in more isolated and less productive areas.

For very small countries, total domestic demand of imports or supply of exports may be insufficient to overcome the economies of scale needed for international trade. For example, imports of fertilizer may be scaled by the number of shipping containers, which can raise costs for importers to small countries where the marginal cost of a partially unused container is relatively high. The fertilizer/grain price ratio in Africa is twice as high as in Latin America or Asia, due to poor infrastructure, the cost recovery needs of input suppliers, and the high level of government intervention in grain output markets (Croppenstedt et al. 2003). Input suppliers may charge high prices to recover costs, and also to compensate for the low volume and high variability of demand in many input markets. Large packaging sizes of standard inputs, such as fertilizer, lower costs to the distributor. At the same time, they force farmers to purchase more of the input than they need, which lowers adoption because of risk and financing constraints (Makokha et al. 2001). In some settings, government policies prevent the repackaging of certain inputs to control quality and prevent adulteration (Kelly et al. 2003). While smaller package sizes might be better for the farmer, many agricultural products have substantial economies of scale in import or export that make transacting in small quantities of inputs or outputs unprofitable for the private sector. Similar challenges are associated with the adoption of mechanized farming technologies. Mechanization saves labor and can facilitate dramatic increases in yields, yet adoption is not cost effective for a single small farmer. Thus, secondary rental markets, together with associated contractual arrangements, are required for mechanization to succeed. Where population densities are low and contract enforcement weak, the necessary rental markets may not emerge (Pingali 2007).

Farmer organizations have the potential to address many of the adoption constraints associated with input and output market inefficiencies, such as improving farmer bargaining power, aggregating demand, reducing individual risk, decreasing transaction costs associated with marketing, and improving credit access.[9] In many settings, farmer organizations can enhance smallholder competitiveness in larger markets, as demonstrated by their rapid expansion in many developing countries over the past two decades (World Bank 2008). However, the challenges faced by these organizations are numerous and include legal restrictions, low managerial capacity, elite capture, exclusion of women and the poor (Baser 1998), and a lack of recognition by the state. Producer organizations may lack the capacity to fill the roles demanded by output purchasers, such as quality and quantity assurance, regulating the timing of output delivery, and assembling products for sale.

Within a farmer organization, inequality of asset ownership affects how much of the profit different members are able to extract, an effect that has been shown to increase with heterogeneity in wealth (Banerjee et al. 2001). Evidence indicates that smallholders may benefit less than larger landholders from the establishment of grower cooperatives. In addition to concerns about benefit-sharing within the cooperative, a potential trade-off between efficiency and inclusiveness faces farmer organizations where financial viability demands a focus on productivity, while social factors may push for inclusion of less productive farmers (Bernard et al. 2010; Chen et al. 2010). Heterogeneous memberships further increase the difficulty in meeting all members' needs and may result in arrangements that benefit the more powerful members. While women may find it easier to have an equal voice within female-led farmer groups, survey evidence suggests that groups with predominantly female memberships have less success with marketing efforts than more male-dominated groups (Barham and Chitemi 2009).

Public sector involvement in input and output markets may be necessary to overcome unprofitable conditions, though government service provision has the potential to create a barrier to private sector entry due to threat of future regulation or distortions on demand. Much public sector involvement in input and output markets happens through agricultural extension services, which suffer from poor economies of scale and weak incentives for extension agents. Barriers to effective extension provision include large geographic areas of coverage exacerbated by poor infrastructure and microclimate variation, and difficult to trace impacts that create accountability problems (Feder et al. 2001). On the demand side, individual small-scale farmers may not recognize the potential benefits offered by extension, have limited purchasing power, and may not be organized to access services. On the supply side, few institutions are capable of providing technical extension services. The private sector may find extension services unprofitable because of the difficulties in charging for information or training that can easily spread beyond the immediate recipient (Anderson and Feder 2007).

[9] If coordination failures cause small farmers to bypass many profitable investments, then we would expect to see larger farmers buying land and resolving coordination failures through aggregation. To the extent that this does not occur, it may be either that land market problems prevent land reallocation (see Section 3) or that the gains from better coordination are modest. While transferring land to larger landholders is likely to help overcome adoption constraints that stem from coordination failures, such a solution does not necessarily benefit small farmers.

Open Pollinated Varieties (OPV) are an example of a technology that is hindered by distribution problems because it does not offer a clear profit opportunity to distributors: seeds reproduce on their own so that farmers do not have to purchase them every season (Kelly et al. 2003). In addition, product development undertaken by the public sector does not have the same market feedback loop that helps the private sector develop products that meet consumer demand—though public sector investment is often better able to incorporate externalities and public goods. Farmer involvement in setting breeding objectives may lead to selections that consider factors other than yield, such as timing of the harvest or quality of the grain (Ortiz-Ferrara et al. 2007). But participatory approaches to technology development (e.g. participatory varietal selection) is not well understood in part because participatory agricultural programs are often bundled with inputs such as information and access.

Crops that rely on more complex marketing chains will be disproportionately affected by input and output market inefficiencies. For example, Ashraf et al. (2009) describe the failure of an export crop intermediary to assure the long-run viability of an export market before encouraging adoption by farmers in Kenya. Crops that are extremely timing-sensitive in distribution or that must meet ouput standards are least likely to be taken up if markets, intermediaries, and storage facilities are unreliable. Without intermediaries that foster trust and build reliable supply relationships, smallholders may be unable compete in supermarket and export markets. Findings to date suggest that better off farmers are better able to participate in modern supply chains, and that participation can increase income 10 to 100 percent, which points to the potential for a widening gap between asset-poor smallholders and better off farmers (World Bank 2008). In a survey-based study of agricultural value chains in India, Fafchamps, Hill and Minten (2008) find that product quality information, particularly related to unobservable product attributes, is not conveyed through the value chain. Thus, quality is not contracted upon and potential price premiums for quality are lacking in these markets.

In spite of the challenges to private sector value chains, many developing countries are undergoing a transformation of their agricultural markets as downstream purchase is consolidated through the rise of supermarkets and the lowering of trade barriers for agricultural exports (Reardon and Timmer 2007). Consolidated purchasers often contract directly with farmers or through wholesalers, and may offer a way around financial and other barriers to adoption by providing credit and other inputs as part of the output contract. However, farmer cooperatives or other types of organizations are often required to ensure the volume, cost, quality, and consistency requirements of these purchasers. As discussed, these organizations face their own challenges.

2.2 What is known about ways to overcome input and output market inefficiencies?

Physical and technological drivers of input and output market inefficiencies are often difficult to address at the micro level for reasons discussed above. In the face of adoption constraints associated with a lack of publicly supplied rural infrastructure and low levels of private sector involvement, alternative actors such as producer organizations or non-governmental organizations may improve distribution channels. On the other hand, jumpstarting private sector supply chains and improving public sector distribution may offer more sustainable solutions. For example, a project in Malawi offers subsidies for access to public transportation to market centers to evaluate the elasticity of demand for those services, and ultimately the impact of better market access on adoption outcomes (Goldberg, Mueller, Thornton and Yang, forthcoming). Such programs may spill over to the supply side as a direct response to the stimulation on the demand side. Alternatively, targeting-associated constraints, such as leveraging information technology to reduce transaction costs, may help farmers overcome existing inefficiencies. Approaches to improving input and output market efficiency involve stimulating and stabilizing demand for inputs, which is likely to improve the function of input supply chains, as well as direct interventions to improve the supply side.

Subsidies can be helpful in stimulating the demand side of agricultural value chains, but are often distortionary or politically motivated and may deliver the benefits to those who are least in need or may be valued below their provision cost (e.g. Pletcher 2000). Better targeting of subsidies through screening or targeting mechanisms can help ensure that the subsidies go to those who would not have otherwise taken up the product, and can generate the initial volume required to set up supply networks and lower prices. For example, in Malawi, distributing fertilizer vouchers to those who had participated in a public labor program appears to have screened for relatively poor households (Kelly et al. 2003). Subsidies may also impede the development of private sector distribution channels. In Rwanda, private sector actors refused to import fertilizer for distribution until the government passed legislation outlawing the distribution of free or heavily subsidized fertilizer by aid organizations. An additional, often cited concern is that subsidies crowd out future willingness to pay for inputs. Research by Pascaline Dupas (2013) on subsidized bednets in Kenya shows that subsidies stimulate future demand by creating greater initial take-up, which gives neighboring families a chance to learn about the value of the technology. Additional research is needed on how to design subsidy programs and when they are most appropriate.

Large scale input subsidies are more often used for food security purposes than for demand stimulation. Malawi's fertilizer and seed subsidy program has received substantial attention for boosting maize production and addressing famines. While impacts on productivity are unambiguous (Denning et al. 2009), administrative costs are high and growing. The economic returns to the program are estimated to be modest under its current formulation, though improvements in implementation, including targeting, could improve its efficiency (Dorward 2011). Benefits from agricultural subsidies during the later stages of the Green Revolution in India are less ambiguous in their success. Bardhan and Mookherjee (2011) use panel data from West Bengal to evaluate the effect of subsidized farm inputs on productivity. They estimate village average effects and find increases of over 45 percent. Results are robust to endogenous program placement and far exceed the impacts of other programs going on at the same time including land tenure reform.

While subsidizing certain inputs may help increase demand or enhance food security, pricing other inputs, including agricultural extension, can help raise revenue and eliminate wastage. If demand is inelastic, then small price increases will have little effect on demand and resulting revenues that can be translated into quality improvements. On the other hand, pricing may result in exclusion of the poor. Literature that tests the effects of on-demand pricing on take-up of public health products is inconclusive, with some evidence that a positive price screens out those least likely to use a technology, reducing wastage (Ashraf et al. 2010). Others find that free provision results in substantially greater take-up, particularly among the very poor (Kremer and Miguel 2007; Cohen and Dupas 2010). Other behavioral factors, such as sunk cost fallacies, framing, or pre-commitment associated with great use are not empirically supported (Ashraf 2010; Dupas 2009). Considerations of the effect of price on purchasers' perception of quality (e.g., Heffetz and Shayo 2009) have not been tested in contexts relevant to agricultural technology adoption. The dynamic relationship between pricing, adoption, and demand for agricultural technologies deserves further research.

Demand stimulation may come in any number of forms, some of which may function through social pressures and other psychological factors. The desire to conform to the behaviors of other farmers appears to have a positive effect on agricultural technology adoption that goes beyond social learning in Madagascar (Moser and Barrett 2002). Conformity around technologies that require coordination may help improve adoption outcomes. Behavioral economics research has also shown that default options can play an important role in coordinating behavior (Choi et al. 2003). In settings where coordination is required to, for example, generate sufficient demand to improve input markets, changing the default may have a large effect on average behavior. Farmer organizations may be influential in affecting "defaults" such as providing pest-resistant seeds as a default input to its members. Changing default options may also be feasible for targeted subsidies like vouchers. Such approaches still allow farmers to opt out should they prefer a traditional technology, but evidence shows that such defaults have a significant impact on behavior. Default interventions may also help overcome other psychological barriers to adoption, though more research is needed on the role of defaults and other behavioral interventions to help coordinate behavior.

Better coordination within an organization or community may be achieved through capacity development for producer organizations (Reardon and Berdegué 2002). Interventions to improve producer organization effectiveness are common, though few have been subject to rigorous research to generate generalizable lessons. In particular, little is known about how to address inequalities and skewed benefit sharing within these organizations. One straightforward approach to overcoming adoption constraints that stem from coordination failures is to aggregate property ownership to reduce the diffusion of benefits from fixed investments. However, whether such an approach benefits small farmers will depend on land and labor markets (Sections 3 and 4). To the extent that coordination failures among smallholder farmers can be overcome through external intervention other than aggregation, benefits are more likely to accrue directly to the small farmers.

Overcoming supply problems in input markets may require demand-side interventions. For example, fee-for-service arrangements for extension services or technical inputs makes service providers accountable to the buyers of the service, and has the potential to address problems with free riding by farmers who have not paid for the service. In practices, willingness to pay for fee-for-service arrangements has been slow to emerge in many settings (Anderson and Feder 2007). In addition, if the poor have lower willingness to pay, they will not be reached, particularly if the timing of input demand coincides with periods of liquidity constraints (see Section 5). A possible solution is targeting public extension for the poor and marginalized (Saito and Weidemann 1990). Another approach to ensure coverage of the poor involves vouchers for extension services, though experiences to date have met with little success (Rivera and Zijp 2002).

Improving coordination of public service providers has been subject to substantial research that focuses on accountability and monitoring of health workers and teachers in developing countries (Banerjee and Duflo 2006). These studies may offer lessons for improving public agricultural extension provision. For example, a randomized trial that used cameras with tamperproof date and time recordings to monitor teacher attendance reduced absences by half by decreasing monitoring costs and depersonalizing the monitoring process (Duflo et al. 2012). Devolution of control over service providers to beneficiaries is often proposed as a way of improving service provision and coordinating supply with demand (World Bank 2008). In some West African settings, giving farmers' associations control over agricultural extension services has been reasonably successful, though the provision of service becomes more expensive as economies of scale diminish (Anderson and Feder 2007). Similar approaches in other sectors show promising results. For example, an evaluation of community involvement in the monitoring of health workers in Uganda showed a dramatic improvement in both health worker effort and health outcomes (Bjorkman and Svensson 2009). These results do indicate that beneficiary control can generate service improvements, though additional research to pinpoint the mechanism for how community involvement leads to improvements will enhance the generalizability of the findings.

The lack of accountability of public sector supply extends all the way up to the product development stage. Many have advocated that greater farmer involvement in setting breeding objectives in these programs can lead to selections that consider factors other than yield, such as timing of the harvest or taste of the output (Ortiz-Ferrara et al. 2007). Improved access, yields, and income have all been attributed to participatory plant breeding and selection. However, whether the apparent success of participatory agricultural programs is due to participation or to bundling with other inputs, such as information and access, remains unknown and a priority for future research. Furthermore, though participatory varietal selection can increase adoption it may not be cost-effective (Walker 2008). Though participatory agricultural technology development may help address both profitability and preference base appropriateness constraints, the relationship between participation and take-up is not well understood and no rigorous evidence on its performance exists at this point.

Other potential approaches to bolstering input markets include training of rural retailers as agrodealers, providing credit guarantees to agrodealers, and repackaging of inputs into smaller packages (World Bank 2008). Qualitative evidence from repackaging of inputs into smaller sizes in Kenya suggests that farmers may be more willing to try new crops if they can first with small quantities of seeds (Seward and Okello 1999, cited in Kelly et al. 2003). In that case study, demand for the smallest packaging size was high at first but shifted toward larger sizes as farmers gained experience. Smallholders cooperatives and associations allow supermarkets and exporters to contract with a single entity rather than many smallholders, which can reduce the cost of including poor farmers in modern supply chains (Reardon and Timmer 2007). Smallholder participation has also been positively associated with tied credit, technical assistance, and training provided by supermarkets, and other downstream purchasers (Swinnen and Maertens 2007).

A large-scale effort to promote orange flesh sweet potato in Mozambique appears to have successfully overcome input market inefficiencies. This was done by teaching vegetative propagation techniques to households to sustain production without repeated input purchases (Hotz et al. 2011). The intervention compared one year to three years of intensive training, demand generation, and marketing. These interventions were bundled throughout the project, making it difficult to determine which was most effective in generating take-up. In both treatment groups, vitamin A intake increased significantly, suggesting that the shorter duration intervention was sufficient to generate take-up. Take-up comes largely from substitution of standard sweet potato varieties for the improved variety (de Brauw et al. 2011). The project also taught households how to market orange fleshed sweet potato vines and sell the sweet potatoes. Significant increases in sales due to the bundled intervention were found, particularly in areas with strong demand for the product.

Tied extension or credit may offer a way to coordinate input and output supply and demand between farmers and distributors, who provide technical know-how, credit, and distribution in exchange for a margin on agricultural output. Tied contracts overcome some of the difficulties associated with weak contracting environments, but face challenges in implementation. In the past, the problem of farmers reneging on tied contracts was (partially) solved by laws requiring farmers to sell to agricultural boards that could discount the amount of any loans for inputs from the sale. But having only one buyer introduces new inefficiencies, and drives down prices for farmers. Tied extension is still seen when there are natural local monoposonies—i.e. where it only makes sense for a farmer to sell to one purchaser of a product, or where contracts are enforceable or interactions are repeated over many seasons. Adoption of new technologies may be higher for products and areas where these local monoposonists exist (Brambilla and Porto 2010). Consistent with this, liberalization has, in many cases, been accompanied by a reduction in agricultural input use (Kelly et al. 2003). Solving input and output coordination problems for farmers that grow staple or subsistence crops (who are often the more marginalized) is much harder and requires more creative solutions.

ATAI is supporting several research initiatives to address input and output market inefficiencies. Duflo, Kremer, and Robinson will explore the distribution of subsidies through local social groups such as churches and schools. This approach allows for targeting of the subsidies and also decreases the cost of distribution. Findings from the study may indicate a scaleable approach to subsidizing socially beneficial agricultural technologies in the face of distribution problems. The same study will explore whether a complementary technology that helps guide the farmer in applying the correct amount of fertilizer improves adoption and yields. Earlier work by the authors found that misinformation about appropriate application techniques presents a barrier to fertilizer adoption. In a pilot project, Miguel and co-authors will attempt to integrate the distribution of weather insurance into the agricultural supply chain. By leveraging existing supply networks, the approach may overcome the distribution problems associated with new technologies.

In other ATAI-funded work, Magruder and c-oauthors will investigate the potential for linking government extension agents in Malawi with the social networks that exist at the village level, improving the distribution of publicly provided agricultural inputs by making extension workers more accountable. Casaburi, Kremer, and Mullainathan will test the effectiveness of decentralizing decisions about input purchases to sugar outgrowers. Letting the individual farmers decide what input combinations are most appropriate for their fields and practices may help overcome input and output market inefficiencies. In yet another project, Glennerster and co-authors will test whether communities with an initially subsidized price for new rice varieties are more or less likely to purchase and plant the new variety at commercial rates in subsequent years. By varying pricing of the new crop technology, the pilot project will evaluate the impact of subsidies on long run demand, and therefore generate findings relevant for private sector distribution networks.

De Janvry and co-authors will seek to help overcome problems of contract enforcement and collective action in Senegal. Their pilot project will facilitate partnerships between organizations of smallholders and commercial actors to monitor members' behavior and to enforce rules. Casaburi, Reed and Suri will pilot the potential to introduce quality contracting into cocoa export markets in Sierra Leone.

3. Land market inefficiencies

The market for agricultural land is limited or missing in much of sub-Saharan Africa, which has important implications for technology adoption. Lack of tenure security, which may or may not require formal titling arrangements, undermines incentives for long-term investment (including irrigation, fallowing, and planting tree crops: see Ali et al. 2011). A lack of formal title often means farmers cannot use land as collateral to borrow, and cannot sell land to raise financing for investment in technologies. Since the rural poor often have more of their wealth in land, the nonfunctioning of land markets affects them disproportionately (Banerjee 2006). Within the household, women may also have less tenure security than men, which makes them less likely to invest in certain types of agricultural technologies (Goldstein and Udry 2008). Evidence is beginning to emerge on potential substitutes for the traditional role of land title in financial markets. Additionally, risk coping offers insights into how asset barriers may be overcome, though further research is needed.

Other than land sales, a variety of arrangements for transferring agricultural production rights are found around the world, including share tenancy and rental markets (Otsuka 2007). Where output-sharing agreements between landlords and tenants are common, lowering monitoring costs has the potential to improve incentives for productivity-enhancing technology adoption. Approaches to reducing the surplus extracted by landlords and to increasing landholder investment incentives may help to overcome the barrier to adoption created by weak land tenure arrangements. While a multitude of studies have shed light on the relationship between property rights and technology adoption, less is known about how to overcome the constraints imposed by land market problems. Where all other markets, such as labor and capital markets, function perfectly, theory indicates that land markets are required for strong adoption incentives. However, the interaction of incomplete land markets with other types of market failures impacts a household's ability to allocate labor (Section 4), smooth consumption (Section 6), and to access credit (Section 5). In addition, if property cannot be freely traded, than standard approaches to addressing externalities (Section 1) may not be viable. Many of the relevant approaches to overcoming land market imperfections presented therefore arise in other sections.

3.1 What is known about land market inefficiencies and technology adoption?

In theory, well-functioning land markets improve efficiency by allowing more productive users to accumulate more land. A variety of institutions other than ownership transfer use or production rights, including share tenancy and fixed rent tenancy (Otsuka 2007). However, tenancy arrangements often create disincentives to invest in productivity-improving technologies because output is shared with the landlord, and insecure tenure decreases the value of long-run profits.

Relative to output sharing, land rental markets should create strong investment incentives by making the renter the full beneficiary of increases in productivity. Rental arrangements fall at one extreme of the spectrum of production arrangements that trade off incentives and risk sharing. Rental contracts place all of the risk associated with agricultural output on the tenant, wage contracts place all of the risk on the landlord, and share contracts share the risk between them. Less risk comes at the expense of less incentive to invest in productivity improvements. Consequently, rental contracts generate the greatest incentive to invest.[10] Under share tenancy, on the other hand, risk is shared and the tenant has better information than the landlord about actual investments in productivity. Because it is costly for the landlord to monitor the tenant's behavior, landlords may be less likely to invest in technologies that are hard for the landlord to observe, such as application of an herbicide (Bardhan and Udry 1999). Profitable technologies may therefore go unadopted because of this information uncertainty. Monitoring and supervision costs also affect the choice of labor in agriculture, as summarized in Section 4.

The institutions that govern landholdings emerge in some cases to address incentive problems and constraints, though historical arrangements also play a role in shaping existing institutions (Banerjee and Iyer 2005). Regardless of the source of the institution, many parts of the world are characterized by insecure land tenure even where formal titling arrangements are clear. Insecure property rights are commonly associated with lower investment in agricultural productivity (Deininger and Sougqing 2001). In particular, investments with long payback periods, such as tree crops, are least likely to be adopted because by the time that benefits are generated, the land may have changed hands (Do and Iyer 2003). Similarly, under insecure formal or informal tenure institutions, investments that potentially lower land security, such as fallowing or agroforestry systems, may not be adopted because of the threat of expropriation (Goldstein and Udry 2008). Expanding formal property rights is associated with increased investment (Do and Iyer 2003). As summarized by Udry (2011), the relationship between traditional tenure rules and incentives for investment is complex and varied. For example, in the same region that saw substantial long-run investment in cocoa production, the same farmers were unwilling to invest in soil fertility because of the informal security that accompanied active crop production (Udry 2011; Udry and Goldstein 2008).

Formal land title is, most fundamentally, associated with the ability to transfer land to the most productivity users. The debate around the relationship between farm size and productivity has proposed numerous potential channels underlying an inverse size-productivity relationship (e.g. Bardhan 1978). Casaburi, Kremer and Mullainathan provide recent evidence on this debate using data from a large contract farming firm and find evidence that smaller producers are more productive. They also find that negative shocks increase the number of small and

[10] The principal agent model of tenancy that trades off the riskiness and the returns to technology has some empirical support (Pandey 2004), though the predicted optimal contract design under share tenancy is rarely observed. Most share contracts are linear in the sharing rule and cluster at 50 percent or two-thirds (Conning and Udry 2007), due at least in part to monitoring and management difficulties.

relatively more productive growers, which suggests that the negative static effects of shocks may be offset by a dynamic efficiency gain via changes to land allocation. The productivity relationship they find may be specific to their setting: sugarcane production in Kenya.

While formal title and complete land markets may not always be necessary for tenure security, they can help ease other constraints such as access to credit and coordination failures. On the other hand, formal titling processes interact with customary tenure arrangements and may be disadvantageous to less powerful actors, particularly women farmers. Efforts to improve women's outcomes from titling have met with mixed results (World Bank 2008). For example, land titling may decrease women's land rights if title is awarded to men while women previously had customary rights to the land, or if women only receive rights when legally married (Ali et al. 2011). In Kenya, land allocated by villages is more gender-balanced than land titled through a legal process (Saito 1994). Increases in the productivity of land due to the introduction of a new technology may also cause women to lose access. Those with less access to information may also benefit less from land reforms. The general finding that land reforms have little impact on investment and productivity may have to do with a lack of information about newly awarded rights (Deininger et al. 2008).

Though land reforms may not address social inequalities or perceived tenure security, customary arrangements are not necessarily egalitarian. For example, in Ghana, those with greater social and political influence are shown to make greater investments in land productivity (fallowing) because of extreme land insecurity that makes others unwilling to leave their land fallow due to the risk of expropriation (Goldstein and Udry 2008).[11] Lower levels of productivity on land cultivated by women in this setting can be explained by shorter fallow periods due to less land security. This also suggests that within the household, tenure security is lower for women than for men, which means that a model of household decision making that treats the household as a single unit does not apply. Croppenstedt, Goldstein and (2013) review the literature on gender and agricultural productivity and demonstrate the fact that women participate less in formal land markets than do men in developing countries. They discuss potential reasons, including cash and credit constraints. The paper offers a valuable overview of the research, and cites numerous related studies.

3.2 What is known about ways to overcome land market inefficiencies?

Interventions that improve trade in land rights are likely to improve adoption incentives, since those best able to make productivity investments will value the land most. Improved trade can also ease inefficiencies associated with externalities. Land reforms are credited in some places with increasing security and

[11] The study differs from other investigations of the relationship between tenure security and investment that find little or no effect because of the high degree of land insecurity in their setting, the use of de facto rather than de jure rights, and the focus on an investment that is accessible to all and is not affected by other barriers.

providing additional productivity investment incentives (Banerjee et al. 2002). On the other hand, these outcomes could be due to the effects of the reforms on other constraints such as credit access (Rogaly et al. 1999). A roll-out of formal land titling in Rwanda that followed a spatial discontinuity generates causal evidence on the effect of a formal title on a number of outcomes (Ali, Deininger, and Goldstein 2011). The researchers find that titling increases long-run investments in soil fertility, particularly among female- headed households. Title also had positive impacts for gender equity, improving land access for married women, and reducing gender biases in inheritance. For unmarried women, on the other hand, the titling process had the effect of crowding out their de facto land rights. Finally, the level of activity in local land markets declined following titling, which suggests that negative distributional impacts were small.

Most studies of formal title are not so well identified. For example, Bellemare (2013) uses detailed soil quality controls to compare the effect of formal and informal land tenure on productivity in Madagascar. He uses cross sectional data with extensive controls and, in some cases, household fixed effects to address omitted variables. The author also instruments for land title with a variable indicating how the plot was acquired (gift/inheritance vs. purchase/cleared). The instrument is questionable with respect to its exogeneity. With the fixed effects specification, formal land rights have no effect on yields, but the relative security of different types of informal rights does appear to affect yields. The heterogeneous response to different types of informal rights (leasing, sales, inheritance, etc.) is not robust across specifications. The World Bank indicates that a number of other roll outs of land titling policies will lend themselves to more rigorous evaluation to generate further evidence on the implications of formal title for technology adoption.

Efforts to invest in productivity may be rewarded by strengthening of individual rights according to communal rules, creating an additional investment incentive (Otsuka and Place 2001). In areas with customary or communal tenure arrangements, indigenous rights are found to grow stronger with land scarcity (Place and Migot-Adholla 1998). Improvements in rental markets have also been shown to increase investment and generate productivity gains (Deininger and Jin 2005).[12] In some cases, simply offering better information about existing institutions governing the use of assets may increase the capacity to invest in agricultural technology (Deininger et al. 2008). Strengthening of land security may take many institutional forms, and the mechanism through which security leads to investment deserves further research.

In tenancy settings, a variety of approaches aim to create incentives for investment by tenants while minimizing monitoring costs by landlords. These include dynamic incentives such as future payoffs or punishment.. A threat of tenant eviction is an example of a dynamic incentive that increases effort but may decrease investment in long-term productivity. Personal and long-term relationships may lower monitoring costs and can improve investment incentives by making the

[12] A lack of rental markets, often the result of weak or unclear tenure, increases the likelihood of distress land sales, discussed in Section 6.

tenant more interested in cooperating with the landlord. Monitoring costs are a common cross-cutting element of barriers to technology adoption.

Among the entrenched, institutional foundations of land market barriers to agricultural technology adoption, leverage for overcoming the barriers and increasing farmer capacity to adopt in spite of limited assets is most likely to come from targeting other, associated barriers. Where share tenancy is common, approaches to reducing the surplus extracted by landlords and increasing landholder investment incentives remain a priority. Differences in land holdings and tenure arrangements affect the majority of the barriers to adoption described in this review. For example, collateral substitutes can improve credit access by farmers who lack property rights that allow them to use land for collateral (Section 5). Payments for environmental services may assist with externalities problems in the absence of clear land markets, though property rights may also be a precondition for institutional arrangements to address environmental externalities. More generally, improvements in the functioning of land markets can facilitate the transfer of productive assets to more efficient users (those less affected by other market failures). Substitutes for the traditional role of capital assets in financial markets (Section 5) and risk coping (Section 6) are examples of how asset barriers may be overcome, though further work is needed in this area.

4. Labor market inefficiencies

Both the accumulation and allocation of human capital plays an important role in technology adoption. For example, education levels are highly correlated with adoption rates in agriculture (Weir and Knight 2003), and the benefits to the farmer that come from having more education increase with the pace of agricultural technology change (Foster and Rosenzweig 1996). Distortions in output and labor markets may mean farmers or workers do not gain all the benefit of their improved productivity, which can undermine the incentive to invest in human capital accumulation. Inefficiencies in allocation of labor directly affect incentives to adopt new technologies. Profitable technologies can increase the productivity of labor and allow for more off-farm labor income (Huffman and Orazem 2007). However, where local labor markets are seasonal and characterized by involuntary unemployment, the incentive to adopt labor-saving technologies is diminished. At the same time, technologies that require additional labor may not be adopted if hired labor is more expensive than household labor. This is because the household bears the transaction costs of labor market participation (Roumasset and Lee 2007).

New technologies also affect the distribution of labor within the household. If female labor has a lower value on the labor market, households may adopt technologies that place a greater burden of time on women than on men (Doss 2001). Consequently, labor-saving devices may be more important for women than men in some cases. Lowering monitoring costs, improving information flows, and developing self-enforcing contracts all have the potential to help local labor markets function more smoothly and increase individual incentives to adopt new agricultural technologies. Current research on these approaches leaves many questions unanswered, particularly on how to ensure that women can access and benefit from new technologies.

Low population densities and poorly developed rural infrastructure contribute to inefficient labor allocations, which are likely to be exacerbated by poor information flows (Section 7). Labor market imperfections are also related to input and output market failures (Section 2) and lack of finance (Section 5). Human capital and social capital assets affect agricultural technology adoption through the relationship between education levels and information processing, and the greater information availability in settings with high social capital (Section 7).

4.1 What is known about labor market inefficiencies and technology adoption?

In theory, labor market problems impose constraints on agricultural technology adoption both in the short-run (through inefficient labor allocation) and in the long-run (through depressed incentive to invest in human capital). On the allocation side, some technologies save labor for the adopting household while others increase labor demands. Labor-saving technologies are more likely to be taken up by households facing constraints due to limited available household labor and incomplete labor markets. Labor-saving technologies may also be taken up by those with off-farm employment opportunities who can use their freed time for income generation. These technologies put a downward pressure on agricultural wages, which may cause agricultural laborers to seek work elsewhere (Foster and Rosenzweig 2008). Economic growth is typically coupled with an increase in mechanization on farms as the returns to off farm labor increase and the incentives for intensification grow stronger. Sub-Saharan Africa is the only region of the world where mechanization has actually declined in recent decades (Pingali 2007). The agricultural activities that tend to be mechanized first are those that require the most power and least precision (Pingali and Binswanger 1987). Labor-intensive technologies, on the other hand, are more likely to be taken up if households face involuntary unemployment due to lack of off-farm labor opportunities. While these technologies can be beneficial if they increase agricultural output, they may also diminish non-farm development in rural areas.

Even if labor markets work well on average, high day-to-day variability increases uncertainty and transaction costs associated with buying and selling labor for agricultural production (Rosenzweig 1988; Key et al. 2000). The variability is magnified across seasons, with many developing countries characterized by periods of labor surplus followed by extreme labor bottlenecks (Barrett and Dorosh 1996). Because the bottleneck often coincides with the planting season when food resources are scarce, farmers without access to credit markets may have to sell household labor to meet immediate consumption needs (e.g., Moser and Barrett 2002). Consequently, labor may not be available to invest in new technologies at planting time, with labor-intensive crops particularly affected. Recent experimental by Goldberg (2012) shows extremely low labor supply elasticities and no differences in labor supply for men and women during the season of low labor demand in rural Malawi. The study is only implemented during the low season but support the notion of a low marginal productivity of labor during these months.

Labor market challenges are likely to be exacerbated by poor transportation infrastructure and information flows. Consistent with an interaction between infrastructure, information, and labor market constraints, evidence from Nepal describes a spatial pattern to labor specialization associated with distance to urban centers (Fafchamps and Shilpi 2003). The relationship between farm and nonfarm labor supply, demand, and wages all affect the impact of a new technology on household income. Rising relative wages for nonfarm labor may induce innovation in agricultural technology to save labor (Hayami and Ruttan 1985). Migration serves as an important mechanism for maintaining equilibrium in the face of labor-saving agricultural innovation or increased demand for nonfarm labor. Out-migration is typically associated with labor-saving technology (Foster and Rosenzweig 2008). Remittances from out-migrants can further increase the local benefits associated with labor-saving technologies, both by providing insurance against agricultural variability and a source of capital for new on-farm investments (Rozelle et al. 1999; Yang and Choi 2007). On the other hand, agricultural technology that increases productivity enhances returns to agricultural labor, which can reduce reallocation of labor away from farming.

Hired labor may be a poor substitute for family labor because of human capital requirements and work incentives. Whether new technologies lead to more use of hired labor or of family labor will, in theory, depend in part on how easily the labor can be supervised and how easily knowledge of the task can be transferred from one farm to another. Because they are not consumers of the output, hired laborers have less incentive to work hard than do family laborers. Hired labor therefore requires greater levels of supervision and may be better used for verifiable tasks. Empirical tests of substitutability of household and hired labor offer mixed results (Roumasset and Lee 2007). Though piece rate contracts offer incentives for hired laborers to work hard, they are not effective if the technology requires effort other than with speed (Bingswanger and Rosenzweig 1986). Thus, technologies that require more sophisticated labor inputs or specific human capital can be more costly to adopt if labor inputs must be hired because of additional supervision costs.

Accumulation of human capital, such as education and health, can affect technology adoption rates. Education, has potential to increase the returns to agriculture by facilitating technology adoption and innovation (Weir and Knight 2003). Research suggests that more educated farmers are better able to process more general forms of information (Wozniak 1993), to innovate with respect to available technology, and to copy early adopters (Weir and Knight 2003). If early adopters tend to be more educated and better off, then the effect of a new technology may have negative distributional implications: early adopters may receive the majority of the profits from new technologies (Sunding and Zilberman 2001).[13] A survey of how farmers in Ethiopia obtain information about new technologies found that half of respondents receive information from extension workers and one-third from friends and neighbors (Weir and Knight 2003). Less educated farmers are more likely to learn from extension workers, which is consistent with other studies that find more specific information is more effective at inducing technology adoption (Wozniak 1993; Jalan and Somanathan 2008). Where technology is stagnant, education is not an important determinant of productivity, and returns to experience may be higher than returns to education (Huffman and Orazem 2007). However, under agricultural technological change, the benefits associated with additional schooling increase (Foster and Rosenzweig 1996). These benefits may extend beyond the household to generate positive externalities for the community, with returns to education increasing for all members of the community (Weir and Knight 2003) due in part to the learning spillovers discussed in Section 1. Human capital investment is also closely related to informational inefficiencies and technology adoption (Section 7).

Health is another human capital asset that has been linked to low adoption rates for agricultural technologies (Ersado et al. 2004), though the causal direction of the relationship is difficult to determine. Substantial evidence points to a relationship between labor productivity and nutrition and health (Pitt et al. 1990), which may directly relate to adoption decisions. Links between health and productivity suggest potential for a virtuous cycle, with more health investment leading to more agricultural technology adoption, which improves health through

[13] This phenomenon of profits from technology accruing primarily to early adopters is known as the Cochrane treadmill.

greater income, better nutrients, labor savings, and other means. Though a number of studies in agricultural settings have generated exogenous changes in health, few have traced impacts through to agricultural technology adoption. Further evidence on the magnitude and direction of these effects will improve understanding of the causes and benefits of adoption.

While in many cases, women and other disadvantaged groups have less access to productivity-improving human capital investments, in other cases those at a disadvantage may be better positioned to take up new opportunities. In India, research shows that low caste women were better able to take advantage of new opportunities created by globalization than were low caste men because of the traditional institutions surrounding the latter's schooling choices (Munshi and Rosenzweig 2006). Similar institutional constraints may affect the ability of different groups to take up modern agricultural practices. The human capital assets of the individual or household and the traditional institutions that constrain his or her decisions will therefore affect capacities to take up agricultural technologies. Though women often contribute more time to household labor, the fact that their time is lower value on the labor market may lead to higher adoption of technologies that save time for males. Research suggests that women's burden of time increases with adoption of some technologies (e.g. increased need for weeding with the application of fertilizers). Technologies that reduce women's labor demands overall and that give women greater control over labor and output may have greatest potential to improve their wellbeing (Doss 2001).

Beaman, Keleher and Magruder (2012) provide novel experimental evidence that lower wages and fewer opportunities for off-farm agricultural labor for women may be attributed to the referral networks that underlie rural labor markets in many developing countries. They find that women receive fewer job referrals than do men and that women are less likely to refer qualified candidates of either gender. They find evidence that the worse performance of referral networks for women can be attributed to social incentives. These findings may help explain technology adoption patterns where the labor cost of the technology is shared unevenly among members of the household – the shadow price of on-farm labor among women may be lower due to fewer off-farm opportunities.

Differences in bargaining power within the household often arise from differences in earning potentials or from social norms, and lead to a breakdown of the model in which the household is treated as a single decision making unit (e.g. Duflo and Udry 2004; Goldstein and Udry 2008). Profitable technologies may not be adopted if bargaining power within the household is skewed away from the primary beneficiary of a new technology. For example, in the case of improved cookstoves in Bangladesh, Miller and Mobarak (2013) find that women have greater demand for the stoves, but do not have the decision making power within the household to make independent purchase decisions. The more powerful household members may also be unwilling to invest in adoption of technologies that will improve the bargaining position of less powerful members in the future (Basu 2006). Some decisions may be more subject to control by other members of the household, such as those with highly observable outcomes (Ashraf 2009), and new technologies may be allocated within the household to benefit the primary income earners (Hoffman

2009). Poor substitutability of labor across genders is demonstrated empirically by differences in agricultural tasks and labor market wages for men and women (Bardhan 1985). Whether due to cultural restrictions or other rationales for labor division, such differences can lower productivity and undermine some profitable technology adoption (Kevane and Wydick 2001).

4.2 What is known about ways to overcome labor market inefficiencies?

Institutions that support better labor market outcomes, whether through allocation of labor or through investment in human capital, have tended to produce economic growth (Acemoglu et al. 2001). At a microscale, improving gender equality and removing stigma associated with minority groups may reduce labor constraints to technology adoption. Investment in human capital, including general education and specific training associated with new technologies is thought to speed the technology adoption process (Huffman 2001). While education interventions may take a generation to yield benefits, more specific training can provide more immediate increases in technology adoption (see Section 7).

As mentioned above, information asymmetries about the quality of workers may introduce friction into rural labor markets. Beaman and Magruder (2012) use a field experiment in India to demonstrate the importance of screening on hard to observe applicant characteristics in hiring short term labor. Though the study involves applicants for non-agricultural work, similar information asymmetries in worker quality may increase the cost of hiring (and supervising) off farm labor, and may partly explain how labor market inefficiencies drive agricultural technology adoption outcomes. They find that incentives for high quality referrals increase the average quality of applicants and are a cost-effective means of improving worker quality.

Efficient labor allocation is hurt in part by the seasonality of labor demand, so approaches that help smooth labor demand across the agricultural crop cycle may be particularly useful. Safety nets, such as public work programs, can help maintain demand and ensure that labor is valued in rural areas. However, these programs run the risk of undermining local labor markets and disrupting local food supplies (World Bank 2008). In recent work in Bangladesh, Bryan, Chaudhury and Mobarak (2011) offer subsidies for seasonal labor migration. They find that a small conditional subsidy increases the likelihood of migration, with unsubsidized migration continuing in subsequent years, and that adoption of migratory labor has substantial welfare impacts on agricultural households during the hungry season. Further investigation of approaches to improving the function of labor markets may increase technology adoption by reducing the impact of short- and long-term shocks on households labor constraints.

Many of these approaches are closely related to other market failures described in this review. Relatively little research has been done to date on specific approaches to overcoming labor barriers to agricultural technology adoption. However, overcoming financial barriers can lower labor barriers by allowing labor - constrained households to purchase some labor inputs during times of peak demand. Similarly, overcoming risk and uncertainty barriers may reduce the impact of illness and other temporary shocks for adoption incentives. Improved access to transportation infrastructure and information can assist with mobility and the geographic allocation of labor.

Adoption of mechanized agricultural technologies may not be feasible where credit markets are imperfect or where contracting among farmers is difficult to enforce. However, where aggressive policies are pursued to facilitate mechanization, such as for subsidized credit for tractors, the distributional consequences for agricultural laborers may be negative (Pingali 2007). Efforts to encourage the adoption of new technologies may also have unintended consequences on the burdens placed on women's time, particularly if they have lower bargaining power in the household. Overcoming the barriers within households may be important for ensuring that women share in the benefits of agricultural technologies. Intrahousehold decision making remains an area of active research, with little indication of how to overcome the adoption barriers that it creates.

5. Credit market inefficiencies

Farmers often cite lack of capital as a major reason for not adopting a technology that could improve their productivity (Croppenstedt et al. 2003). Imperfect rural financial markets can prevent farmers from borrowing to invest in a new technology and from insuring against the risk associated with experimenting with a new technology. These constraints are likely to be greatest for agricultural technologies that impose upfront costs for switching. Financial barriers go beyond a lack of credit access. For example, in multiple settings, financial products that allow individuals to commit to future saving or investment at the moment when they have cash available, such as immediately following the harvest, improve adoption and other outcomes (Duflo et al. 2008).

Collateral is often used to improve access to financial products because it helps offset asymmetric information and moral hazard risks to lenders. But the poor, particularly those in rural areas, require collateral substitutes. Innovative examples of effective collateral substitutes include supply contracts for farm output (Dries et al. 2004), standing crops, and reputation (de Janvry et al. 2010). Overcoming financial market inefficiencies has positive implications for other barriers to adoption, including risk and uncertainty (Section 6), lack of information (Section 7), and land market failures (Section 5). Further research is needed to identify lending practices that lower the cost of borrowing for agricultural investments. Findings from behavioral economics offer relevant approaches to structuring financial products to most benefit the poor, but have received little attention in the context of agricultural households.

5.1 What is known about credit market inefficiencies and technology adoption?

Credit constrained farmers use significantly fewer high-yielding varietals (Mordoch 1993) and surveys often confirm that farmers perceive liquidity constraints as a major barrier to technology adoption. The lack of available credit and financial services for poor farmers is often due to contracting challenges, to limited liability, and to information asymmetries about borrower type and behavior. These financial problems are particularly pernicious for agricultural households, where monitoring costs are high and cropping cycles result in uneven timing of income and expenditures. For example, liquidity constraints and a lack of credit access in the planting season causes many households to sell labor to meet consumption needs rather than investing in their own farm (see Section 4).

Financial markets in developing countries often display a variety of imperfections that make borrowing difficult for the poor and allow lenders and other financial intermediaries to extract many of the financial gains from technology adoption. Lending and deposit rates are often highly divergent and the interest rate within a single sub-economy may be extremely variable (Banerjee 2006). Rural financial markets are also often highly fragmented, with different rates within a single market assigned according to characteristics of the borrower, the lender and the financed activity (Conning and Udry 2007). Government intervention has, for the most part, been ineffective. For example, the introduction of interest rate ceilings has tended to result in the exclusion of small farmers from borrowing. While lowering the costs of providing credit to the poor is almost certainly desirable, subsidizing credit is not efficient because defaults are likely to lead to increases in the interest rate, based on average repayment (Bardhan and Udry 1999).

Numerous characterizations of rural financial markets suggest the following stylized facts (e.g., Conning and Udry 2007). Monitoring costs due to poor contract enforcement capabilities potentially explain the difference between lending and deposit rates. This gap implies that the wealthy will tend to invest more than the poor, particularly when interest rates differ for these two groups. Low deposit rates for the poor further deter saving and lending, which may in turn deter technology adoption. Savings products are an important way of smoothing consumption, but formal saving opportunities are not always available to the poor because of the transactions costs and regulatory restrictions that banks face. Demand for savings is depressed by low or even negative real interest rates, security concerns, difficult to access banks, and family obligations faced by potential savers.

Lenders are often less willing to finance investments that are more susceptible to information asymmetries, including adverse selection and moral hazard, because repayment rates are likely to be lower on these loans. Moral hazard problems, in which individuals take loans but do not exert maximum effort to repay, can be addressed through collateral. But poor farmers who lack assets such as secure land tenure may be unable to offer the collateral necessary to access credit. Even if farmers have the assets needed to fully collateralize a loan, asymmetric information can lead to rationing of credit may occur on another dimension: risk. If farmers lack access to insurance markets, the terms of a loan may be sufficiently risky that they would prefer not to borrow at all (Boucher et al. 2008). This illustrates one of the complementarities between credit and risk markets.

Adverse selection and limited liability, both of which involve greater demand for loans by the types of individuals least likely to repay, drive up interest rates as default risks increase. In theory, the low cost to reneging for very poor borrowers who have little to lose (limited liability) creates dynamics that may perpetuate income inequalities and affect opportunities to invest in agricultural technology (Banerjee and Newman 1994; Bardhan and Udry 1999). In response to limited liability, lenders may raise interest rates, which simply worsens the problem since only those likely to default will take up a high interest loan in the first place (Stiglitz and Weiss 1981). What little empirical evidence exists on the prevalence of moral hazard and adverse selection in developing country credit markets finds that both are present, though moral hazard is found to be the greater problem (Karlan and Zinman 2009). How to best address these issues remains an area of open research.

Certain types of technologies are particularly difficult for smallholder farmers to finance. Where upfront switching costs are high, the need for access to credit is greatest. Risky investments where the risk is not correlated with easily verifiable measures of borrower effort create a stronger moral hazard incentive and increase monitoring costs for the lender, which are typically passed on as higher interest rates. In addition, technologies, such as irrigation canals or large pieces of equipment, that come in the form of a single large investment will require more upfront financing, which lenders may be unwilling to provide (e.g. Giné and Klonner 2008). Similarly, technologies with long payback periods, such as tree crops, or many other environmentally beneficial investments, are less likely to stand up to the high interest rates typically available to poor borrowers. It is worth noting that many agricultural technologies, such as coffee, have historically been adopted and diffused without access to sophisticated financing mechanisms.

Research in Ethiopia found that credit constraints significantly interfere with fertilizer adoption, but credit constraints are related to other demand-side determinants of adoption such as education, household size, and value-to-cost ratio (Croppenstedt et al. 2003). Consequently, overcoming the barrier of credit access alone may not single-handedly increase adoption. Even where financial products are targeted to the poor, access may not be uniform. In some settings married women cannot gain access to credit without a signature from their husbands (Doss 2001). Access to credit may be biased by lenders' expectations of loan repayment. To the extent that women produce more for home consumption, the perception may be that they will not have cash to repay loans. On the other hand, gender-based lending that strongly favors female borrowers has become popular and demonstrated some success (Ashraf et al. 2003).

5.2 What is known about ways to overcome credit market inefficiencies?

Collateral is a straightforward way to address financial barriers, but for the poor there is a need to find collateral substitutes. Innovative examples of collateral substitutes that have been used effectively include supply contracts for farm output (Dries et al. 2004) and standing crops. Reputation may also serve as collateral, and developing countries have begun to turn toward credit reports for potential borrowers that condition future loan opportunities on past performance (de Janvry et al. 2010). Recent research on dynamic incentives introduced through fingerprinting in Malawi suggest that better technologies for tracking borrower repayment records helps with both adverse selection and moral hazard (Giné et al. 2010). Such innovations may come at the cost of excluding those who face legitimately higher repayment obstacles, such as women or the very poor. A more common collateral substitute is group liability, which uses social capital for collateral and is typically viewed as a useful innovation that reduces monitoring costs and lowers default rates. However, there is little evidence that joint liability performs better than individual liability (Giné and Karlan 2011). Additional adaptation of collateral substitutes to agricultural settings may help lower financial barriers to technology adoption.

Monitoring borrowers can also substitute for collateral when it is offered by an intermediary. In Ethiopia, the government stepped in to play this role, levying severe penalties for credit default, including arrest (Demeke et al. 1998). While the efforts appear to have been relatively successful, they required political will that is lacking in many places. Poor borrowers with little collateral are subject to substantial monitoring, which increases costs and therefore interest rates. Similar to the way that correlated information can help overcome information asymmetries in insurance markets, evaluating the performance of borrowers relative to each other in settings where outcomes are highly correlated (such as crop harvests) allows the lender to obtain a cleaner measure of the borrower's effort based on other borrowers' outcomes (Conning and Udry 2007). Other approaches to reducing monitoring costs observed in practice include lending according to crop cycle, in kind loans from input suppliers, and contract farming schemes. Targeting credit to new market entrants—for example, in export markets—is shown to have a greater impact on income than making credit available to farmers already in the market (Ashraf et al. 2009). However, new entrants may need relatively more monitoring.

Lowering the transaction costs in verifying collateral has potential to improve credit access. Taking advantage of the gradual roll-out of computerized land registries in India, Deininger and Goyal (2009) examine the effects on credit access and find that credit access improves in urban areas, but is unaffected in rural areas. Further research on lowering monitoring and transaction costs and otherwise addressing the information asymmetries associated with adverse selection and moral hazard will assist in overcoming multiple barriers to adoption.

In addition to credit access, other financial products can help farmers overcome financial barriers to technology adoption. The range of financial products available to the poor is expanding to include savings, money transfers, insurance, and leasing. Microfinance institutions are diversifying beyond credit to include savings options that allow for very small deposits. Improvements in information technology can help reduce the transaction costs that make financial transactions costly. Examples include agricultural credit cards for input purchase and cellular banking (World Bank 2008). Though the expansion of these services is almost certainly beneficial, the first clean evaluation of the impacts of microfinance—without a particular emphasis on agriculture—suggests benefits are modest (Banerjee et al. 2013). Crepon et al. (2011) provide even more recent evidence on the impact of microcredit in rural Morocco. They find positive effects of access on agricultural activities, including livestock holdings, sales, and consumption, but little impact on consumption, health, or education. Profits are positive for crops but not for livestock. Results are based on a 13 percentage point increase in credit take-up in treatment villages after two years. Further work on the impact of microfinance and other financial products specifically targeted toward farmers is needed.

Beyond information asymmetries, behavioral factors in decision making may affect financial behavior. Savings commitment devices have been subject to several recent studies that show an unmet demand for commitment products among the very poor. In the Philippines, introduction of a commitment savings product increased savings significantly after one year (Ashraf et al. 2006). In an agricultural setting in Kenya, farmers demonstrated demand for commitment savings products for technology adoption (Duflo et al. 2009). In Kenya, purchasing fertilizer at harvest time when money was available led to take-up by all who express demand, while a few days' delay collecting the funds cut participation by almost half, and waiting until the time that the fertilizer was delivered reduced participation to zero. In comparison with free delivery and price subsidies, the savings commitment brought in new adopters instead of subsidizing those who would have adopted anyway. This has important efficiency implications for how funds are spent. Recent work in Malawi shows the potential of commitment savings accounts for farmers, the majority of whom chose to commit in advance to release funds at the planting time (Brune et al. 2010). Further tailoring recent findings on the behavioral nature of financial decisions to agricultural settings, where income streams are determined by the crop cycle, can help overcome financial barriers to technology adoption.

Other behavioral biases, such as mental accounting or separate household accounts, can lead to inefficient savings behavior if individuals associate certain funds with different expenditures. They may also fail to balance expenditure needs based on the total budget available, basing it instead on an artificial separation of accounts. While no empirical research has been conducted on mental accounting in developing countries or agricultural decisions, separate accounts have been documented for different individuals within a single household. When a crop generates higher than average returns, expenditures associated with the cultivator of that crop increase disproportionately (Duflo and Udry 2004). Financial interventions may be able to help smooth these inefficient consumption patterns, though little research has been done on the design or implementation of such approaches.

While approaches to lowering financial barriers that leverage understanding from behavioral economics are useful, lack of sophistication does not appear to be as important as the relatively high costs associated with the use of financial products by the poor. In a field experiment, Cole et al. (2013) find that demand for financial products increases with the provision of cash incentives but not with training in financial literacy. In a survey that accompanies the experiment, on the other hand, the authors find that low financial literacy is correlated with low demand.

ATAI projects will investigate strategies to overcome the adoption challenge presented by poorly functioning financial markets. In Kenya, Duflo, Kremer, and Robinson will follow up on their earlier finding that present-bias leads to underadoption of fertilizer due to the lag between the harvest time (when cash is most available) and the planting season when fertilizer purchase takes place. The project will explore strategies for scaling up a savings commitment approach. Fertilizer coupons that are only good for a certain period of time will be offered in group settings, such as schools and churches, and will be offered immediately after the harvest period.. In another project in Kenya, Casaburi, Kremer, and Mullainathan will evaluate an approach to overcoming the high discount rates that can deter adoption of crops with a relatively long payback period. Contracted farmers will receive cash advances conditional on farmers' performance at intermediate stages of the harvest cycle. If myopia and credit constraints play a large role, anticipated payments tied to intermediate outcomes should increase adoption.

Also in Kenya, Kremer, Suri, and colleagues will explore the potential for overcoming financial market inefficiencies that impede the adoption of water tanks for dairy producers. The study will compare different ways of overcoming the gap in available credit to farmers, including using the tank for collateral, requiring down payments, and using guarantors to secure loans. The design will allow the researchers to separately identify the effect of the loan innovation on selection (which type of borrower receives a loan) from the effect on repayment incentives.

6. Risk market inefficiencies

The classic view of poor farmers is that their lack of savings to fall back on causes them to prefer approaches with lower average returns but more reliability to approaches to higher average yields with more variability. Adoption of new technologies may be seen as risky, especially early in the adoption process when proper use and average yields are not well understood. These problems are particularly acute where risk-coping mechanisms are not available, and women and men may be affected differently if risks are not shared within the household (Duflo and Udry 2004). The magnitude of the adoption constraints imposed by risk and uncertainty are not well understood. An alternative view suggests that opportunities for risk diversification are more available to poor rural farmers than are opportunities for income enhancement.

Insurance, safety nets, and other risk coping strategies are potential approaches to offset risk market inefficiencies (Simtowe 2006). However, there are important puzzles that suggest the take-up of risk-coping strategies is not straightforward. First, demand for agricultural insurance and other risk mitigation technologies appears to vary substantially across settings and insurance products (Cole et al. 2013, Karlan et al. 2012). Second, in some ways, the poor appear to be overdiversifying by engaging in multiple different sources of income, rather than concentrating on those activities that are most profitable. These behaviors are likely exacerbated by the inability of households to insure and contract between husband and wife. In other ways, farmers undertake too little diversification. Numerous surveys suggest that few farmers, for example, put fertilizer on a portion of their crop when they cannot afford fertilizer for the whole field. Priorities for overcoming risk and uncertainty barriers include better understanding of demand-for-risk mitigation technologies and the design of financial products to smooth risk within the household. These are active areas of current research with many unanswered questions. Additional insights into overcoming risk market inefficiencies may be gleaned from the understanding of decision making under risk and uncertainty offered by research in behavioral economics and marketing. Constraints associated with risk and uncertainty are also closely related to lack of information (Section 7) and lack of finance (Section 5).

6.1 What is known about risk market inefficiencies and technology adoption?

The technology adoption decision may be a discrete problem (whether to adopt at all) or a continuous problem (how much to adopt). Divisible technologies that allow for adoption of small amounts at a time may be less hindered by risk barriers than are technologies that take on an all-or-nothing character. In his review of research on diffusion, Rogers (2003) concludes that trialability, the degree to which a potential adopter can try something out on a small scale first before adopting it completely, is a major determinant of adoption. Thus, agricultural technologies that require large upfront investments, such as machinery or irrigation systems, may be deterred by both imperfect credit markets (Section 5) and by risk and uncertainty. Risk and uncertainty may affect decision making at any stage of the production process, from inputs to storage, processing and marketing.

Households and villages have developed a multitude of informal mechanisms for coping with risk. To the extent that these mechanisms allow households to maintain a relatively constant level of consumption, risk will be less of a barrier to technology adoption. Risk pooling among households within a community or network removes idiosyncratic shocks to income by insuring among households. However, this risk pooling approach will not smooth consumption if households tend to experience bad outcomes at the same time, which is often the case, particularly in agriculture (Conning and Udry 2007). Risks that tend to hit many households at the same time can potentially be mitigated by migration of some family members or placement of fields throughout a landscape (Bardhan and Udry 1999). Empirical tests of informal insurance typically find that households and communities are partially able to smooth consumption in the face of temporary bad outcomes (Bardhan and Udry 1999).

Within a household, credit and savings help smooth consumption over time if bad outcomes are short-lived. Households may also buy and sell assets as another form of income smoothing (Rosenzweig and Wolpin 1993). However, farmer risk aversion combined with credit constraints mean that farmers tend to sell assets in times of distress, when prices are unfavorable and the recovery time is long. Households also mitigate risks by adopting crops or practices with lower yield variance, which is often accompanied by lower expected profits. New technologies that increase yield variance are unlikely to be adopted by a household concerned with risk management. At the same time, households often pursue multiple sources of income to diversify risk, resulting in lower average income than would result from a strategy that focuses on more lucrative income streams (Banerjee and Duflo 2007). Minten and Barrett (2008) show that farmers are most likely to take on a new crop variety if they have other sources of stable income to offset the risk of experimentation. On the other hand, if the expected returns are sufficiently high, farmers may be willing to take on a fair amount of risk — these tradeoffs have not been well calibrated.

Even among members of a single household, consumption smoothing and risk pooling may be imperfect, particularly if men and women cultivate separate crops and generate income from sources subject to different risks, such as different sensitivities to extreme weather (Duflo and Udry 2004). Whether male- or female-held assets (including land) are more negatively affected by shocks may be context specific. New analysis by Quisumbing et al. (2011) suggests that the distribution of impacts within the household of various types of shocks differ substantially between Bangladesh and Uganda. In both places, the impact of shocks are distributed asymmetrically between men and women, though women do not always fare worse. The landless are also likely to be particularly exposed to risk because they have less to fall back on when other income sources fail (Conning and Udry 2007). Risk sharing tends to be better among groups, such as kinship, family, clan, and religious affiliations, which are able to impose higher penalties on one another for defaulting on a risk-sharing agreement (Conning and Udry 2007). To the extent that the landless, the very poor, women, and those lacking a close social network are less well-insured by informal mechanisms, they are less likely to adopt technologies that increase the variance of returns.

The clear demand for risk management and the inadequacy of village networks should, in theory, result in the emergence of financial intermediaries. Contracting problems associated with unobservable components to the risk makes outside intermediaries less willing to offer these services (Conning and Udry 2007). For example, households have better information than does the intermediary about the risk that they bear (adverse selection) and about the actions that they undertake to reduce risks (moral hazard). The incentive problems presented by situations with these information asymmetries are further discussed in the section on financial barriers (Section 5). Contexts with weak contract enforcement and highly correlated risks are likely to leave households most exposed to risk.

Farmers face multiple sources of uncertainty: weather and other environmental factors, supply and demand (prices), distribution networks, and correct use of a technology. How these uncertainties affect adoption ultimately depends on risk attitudes, which are shaped, in part, by a farmer's situation. The relationship between wealth and risk aversion in the adoption decision is ambiguous. Risk preferences combine with limited liability for the very poor, who have less to lose should a bad state of the world occur—which will lead to higher adoption rates, other constraints held equal (which of course they are not). In the context of credit take-up by smallholders in Malawi, Giné and Yang (2009) suggest that risk aversion is not a major deterrent to the adoption of new technologies by farmers who are borrowers: limited liability acts as a risk buffer for the very poor by allowing them to default if crop yields are bad. On the other hand, risk and credit markets interact, with imperfections in the credit market affecting returns to insurance and vice versa (Karlan et al. 2012). Boucher et al. (2008) similarly describe the risk rationing that may undermine credit markets where risk markets are missing.

Weather variation is frequently described as the most important source of risk for smallholder farmers (Cole et al. 2013; Giné and Yang 2009). Since weather is spatially correlated, social networks that are geographically close will be ill-equipped to share risks. Thus, contexts with highly unpredictable weather or a high dependence on the timing of rainfall are susceptible to adoption barriers related to risk and uncertainty. Short-term shocks, such as those created by most adverse weather events, will have long-term effects if formal and informal coping mechanisms are inadequate. For example, the withdrawal of children from schools in Mexico due to temporary income shocks makes children less likely to go back to school the next semester (De Janvry et al. 2006).

Global price fluctuations in commodity crops are another common source of uncertainty, though the relationship between international and local prices depends in large part on the structure of local and domestic markets. Price stabilization is often an explicit objective of government policy and can be effective in reducing uncertainty but often favors consumers over producers, reducing profits to farmers (Abbott and McCalla 2002). Where government intervention is substantial, price policies are found to reduce volatility by over 25 percent (Schiff and Valdes 1992). On the one hand, a disconnect between global prices and farm gate prices buffers farmers from additional price uncertainty; on the other hand, it often results in a much lower farm gate price than border price (Anderson and Masters 2009). Where output prices are volatile, poor storage capacity may exacerbate the impact of price fluctuations (World Bank 2008). Perishable products or crops that are very sensitive to the timing of planting, harvest and marketing are associated with a high degree of risk. Reliable distribution becomes crucial for mitigating risk for these technologies.[14] Crops destined for export markets and modern supply chains often carry quality or production standards that may create more risk for farmers and require reliable intermediaries. Ashraf et al. (2009) describe the collapse of an export market that revealed the underlying uncertainty associated with farmers' dependence on intermediaries in quality controlled markets. These risks may be a significant reason why farmers do not invest in crops for export markets. The small probability of a large loss in export and other uncertain markets may lower the value of a crop, further reducing adoption.[15]

Behavioral economics suggests that individual decisions under risk and uncertainty are subject to irrational biases (Kahneman 2003). For example, prospect theory suggests that individuals weight the value losses more than the value of gains, and tend to overweight small probabilities. These theories may also explain adoption patterns for new agricultural technologies under risk and uncertainty (Liu 2011), though little research on the topic has been done. The distinction between risk and ambiguity aversion may also be important, as recent work by Bryan (2010) suggests. He tests a model of ambiguity aversion in a number of different settings and finds strong support for the explanation that more ambiguity averse households demand less insurance. As the familiarity with the insurance increases, ambiguity decreases, and demand goes up. Additional evidence on ambiguity aversion and agricultural technology adoption is presented by Ross et al. (2012), who use a combination of experimental methods from the lab and survey evidence to show that more ambiguity averse individuals are more likely to adopt improved varieties. Both Bryan (2010) and Ross et al. (2012) rule out that risk aversion alone can explain their results.

6.2 What is known about ways to overcome risk market inefficiencies?

The lack of formal risk markets in developing countries is often attributed to the information asymmetries and high default risks that drive up monitoring costs and insurance premiums. Weather insurance and other index insurances are tied to an observable source of risk that is hard for the policy holder to manipulate. Thus they are less susceptible to problems of adverse selection and moral hazard than are many other types of insurance (Cole et al. 2013). In addition, rainfall is not related to other sources of risk borne by the insurer, such as stock market prices, which should appeal to private investors. Though weather variability is cited as the primary source of risk by many farmers, take-up of such products is not consistently

[14] Barriers associated with distribution and marketing of perishable crops are discussed in Section 3.
[15] This relates to the "peso problem" in macroeconomics, wherein the value of a currency is lowered to reflect the small probability of a large devaluation.

high, even when it is offered at below market prices. The number of experiments testing agricultural insurance products continues to grow, and evidence that risk is a substantial barrier to agricultural investments is becoming clearer. At the same time demand elasticities for insurance products remains high, with raises questions about how to market such products.

The number of field experiments examining the design and adoption of various types of index insurance are growing quickly, with some notable differences in findings. Cole et al. (2013) test a variety of possible explanations for the low take-up rates of weather insurance in India and find that liquidity constraints and price sensitivity are contributors. Those who do purchase tend to purchase a very small amount (hedge 2–5 percent of their income). Cole, Stein, and Tobacman (2011) combine data from the field experiment with a structural model to estimate Indian farmers' valuations of weather insurance. They compare estimates from the structural model to valuations elicited through a Becker-DeGroot-Marschak mechanism, and find that the latter better predicts purchasing behavior. Overall, demand in their experiments is low, though households with more experience with the product were more likely to purchase. They also observe that higher levels of risk aversion are correlated with lower purchase probabilities when the insurance product is first introduced, and higher purchase probabilities as it becomes more widely known. This suggests that the low levels of demand observed in many settings may be due to the lack of experience with the insurance product.

Karlan, Osei, Osei-Akoto, and Udry (2012) find evidence that contrasts with the results of Cole et al. (2012). They conduct an experiment in Ghana that varies farmer access to insurance (at varying prices), cash grants, or both. They find substantial demand for index insurance and a strong effect of insurance on agricultural investments. Risk is found to be more important than cash constraints in determining farmer investments in the study setting, though suggestive evidence points to basis risk and a lack of trust. The findings contrast with previous evidence on demand for index insurance (Cole et al. 2013), which finds low levels of demand and insurance purchases, when they do occur, that cover only a small share of the farmer's risk exposure. Another well-executed example of a study on take up index insurance is Hill et al. (2011), which combines a panel data set with a randomized intervention to elicit willingness to pay for index insurance in Ethiopia. They observe higher demand for the product, offered at randomized prices, from wealthier and better educated farmers, and lower demand from those with higher levels of risk aversion. The insurance intervention also assesses different ways of designing and marketing the product, and finds that reducing basis risk increases take up. Offering the product to groups of farmers is particularly beneficial for take up for women and those with lower levels of education. A recent study by Mobarak and Rosenzweig (2012) shows that demand for index insurance extends beyond farmers to the rural laborers who rely on farm-work as their primary source of income and are therefore affected by weather shocks.

Another source of risk that can be reliably indexed to verifiable common shocks is crop prices. Karlan et al. (2010) explore the impact of crop price uncertainty on loan take-up by randomly offering some loan clients crop price indemnity as part of a loan. They find extremely high demand for loans, which obscures any effect of the risk mitigation treatment. A similar bundling of insurance and credit is offered by Giné and Yang (2009) who investigate the role of possible losses or limited liability for credit demand. They show that mandatory insurance decreases take-up of credit to purchase improved crop varieties. The results suggest that the limited liability of very poor farmers makes the risk of default in a bad state of the world less damaging than for better off farmers with more to lose. To explicitly examine the interaction between risk and credit market failures, Karlan et al. (2012) use a cross cutting design in which some farmers have their credit constraints alleviated, while others are given the change to purchase weather insurance at varying prices. They measure subsequent on-farm investments and find that missing risk markets appears to be the greatest barrier facing their sample of Ghanaian farmers: investments increase under the insurance treatment but not the credit treatment. In addition, they document demand for insurance far above that observed by Cole et al. (2013) in India. In both studies, subsequent demand is increasing in previous years' payout under the insurance contract.

Livestock is a third area where insurable common shocks reduce the potential for moral hazard in the insurance market. Cai, Chen, Fang and Zhou provide additional evidence on the impact of index insurance on the adoption of sows, and find that insurance leads to greater adoption in the next period when insurance pays out during the first year. The authors conclude that their evidence in consistent with low levels of trust in government insurance schemes, and that observing payouts builds trust. The importance of trust in insurance take up is also found by Cole et al. (2012 update). Unlike much of the existing literature, Cai et al. study insurance for individual livestock, where farmers insure individual sows against disease, accident or natural disaster. It also differs in that the encouragement in the randomization consists of incentives to extension workers who promote the insurance in rural areas. Thus, the findings also speak to the relevance of performance incentives for increasing the success of extension workers to promote the adoption of technologies such as livestock insurance.

Growth in index insurance markets may be hindered by a lack of good data upon which to base payouts. In Mexico, payouts for state provided weather insurance are also calibrated by a proxy measure for poverty to better target the service (World Bank 2008). In Mongolia, livestock insurance is indexed to mortality rates for the local area and historical rates, with a guarantee offered to insurers by government (World Bank 2005). A new effort to increase weather data collection in Africa may increase the potential for scale-up of weather insurance (Black 2009). On the other hand, many risks that farmers face cannot be indexed to objective payout measures, and further research on risk mitigation products for risks that cannot be indexed remains a high priority.

The introduction of index insurance may also interact with existing informal insurance networks, as a number of new studies have highlighted. Mobarak and Rosenzweig (2012) investigate whether well functioning informal risk markets crowd out the development of more formal markets, and may explain low levels of demand in previous studies. They generate exogenous variation in the basis risk associated with the formal insurance contract by randomly varying the location of the rainfall gauge. Together with baseline data on existing risk networks, the authors demonstrate that demand for index insurance is decreasing in basis risk, but that informal risk sharing networks help to offset this effect. Dercon, Hill, Clarke, Outes-Leon and Taffesse (2012) also examine the interaction of informal insurance and formal insurance using a field experiment in Ethiopia. Similar to Mobarak and Rozensweig, they examine the role of basis risk and the offsetting potential of informal insurance. Specifically, their model predicts that demand for index insurance is higher in the presence of informal risk sharing arrangements. Their experimental variation is in whether informal sharing of basis risk was emphasized in the training of pre-existing risk sharing groups. They find higher demand for index insurance among groups that received training on informal risk sharing. Informal networks are also shown to play a role in the adoption of demand for insurance in a study by Cai, de Janvry and Sadoulet (2013). The authors combine social network data with random variation in financial education, information about peer decisions and the default option. They find that whether peers adopt insurance matters less than whether peers have financial literacy. They also find evidence that the centrality of an individual to the network affects the dissemination of information.

The design and distribution of insurance and other risk mitigation products may have a large effect on adoption. Where trust is a determinant of insurance adoption (e.g., Cole et al. 2013), insurance may be slow to diffuse at first as the supplier becomes better established. Targeting specific risk mitigation products to women and men separately may also be important for improving risk sharing within the household (Duflo and Udry 2004). The dynamics of demand generation also have implications for optimal insurance contract design. Payouts that are positive on average because they are triggered by very small fluctuations in weather may generate more take-up though catastrophe insurance may be what matters most for farmers. Further testing of these design features will improve the tailoring of insurance products to relevant populations. Basis risk continues to be a barrier to the proliferation of index insurance, as these studies illustrate. As an alternative to complementary informal insurance, Ellabed, Bellemare, Carter and Guirkinger (2013) propose a multi-level contract, which mitigates basis risk at each level. The demand response is simulated using experimental data from a number of existing index insurance field experiments, but the actual contract is not tested.

Mitigating risk through formal mechanisms (such as index insurance) offers one approach to reducing risk and uncertainty barriers. Marketing research points to a number of other techniques to reduce risk, including advertising, demonstrations, money back guarantees, salespeople, and warrantees (Aker et al. 2005). Money back guarantees are thought to be less efficient than other marketing tools aimed at adoption because they require that the purchase takes place. Warrantees, on the other hand, reduce post-purchase risk and can be tailored to fit particular agricultural settings, such as quick repair guarantees for machinery used with timing sensitive crops. These marketing approaches may be less relevant for rural areas with poor access to markets and product support centers. On the other hand, product trials have been shown to increase adoption in developing countries (Sunding and Zilberman 2001). Adaptation of the insights available in marketing research offers a promising direction for overcoming risk and uncertainty barriers to technology adoption.

A recently supported ATAI project will explore alternative approaches to making weather insurance available to farmers in an effort to offset risk and uncertainty barriers to technology adoption. The pilot, led by Miguel and co-authors, will evaluate a program in Kenya in which farmers purchasing inputs (such as seeds and fertilizer) from certain suppliers can opt to pay a small premium that insures the inputs against drought or excess rain, with the insurance indexed to measured rainfall at the weather station closest to the farmer. This program has several potential benefits: farmers can experiment with very small amounts of insurance; they work with familiar input suppliers; and input suppliers pay 50 percent of farmer insurance premiums (and in return only the inputs of participating suppliers are insured), which will reduce premiums. Moreover, the strategy of insuring inputs directly and distributing insurance through existing agricultural input supply chains could prove particularly effective at encouraging the adoption of other agricultural technologies.

Another ATAI pilot, led by Karlan and Udry and based in Ghana, will explore the relationship between fertilizer (organic and inorganic) adoption and farmers' exposure to risk. In earlier work, the investigators identified low levels of fertilizer adoption as a major constraint to more intensive cultivation. The pilot will compare different barriers to fertilizer adoption, including risk and information, and will examine the potential for organic fertilizer to improve yields alone, or in combination with inorganic fertilizer.

Sadoulet and colleagues will investigate strategies for increased take-up of a submergence-tolerant variety of rice. It is better able to withstand rainfall variation, and therefore a useful technology for climate change adaptation. The technology also has implications for fertilizer management. A randomized evaluation in two states in India, implemented in collaboration with IFPRI, will examine whether the lower risk associated with the rice variety leads to greater (fertilizer) inputs, as well as the role of information in these adoption decisions.

7. Informational inefficiencies

Technologies that are individually profitable will not be taken up without information about their profitability or about how to correctly use them. Information about new technologies comes from a variety of sources: farmers' own experience, neighbors' decisions and experiences, and external sources such as extension workers or the market. Generally, technologies that are technically complicated or require precise implementation will suffer most from information barriers due to low or negative expected profits if used incorrectly. New research suggests that the way information is presented (i.e. who provides the information, how much information is given, and in what form) can be as important as the content of the information itself. Certain groups, such as women, may face larger information barriers if information is less accessible to them. Lack of information may present a barrier on both the demand and the supply side, and a lack of information about the latent demand for a technology may contribute to input and output market inefficiencies (Section 2) and low levels of adoption.

Strategies for overcoming a lack of information often involve making information less costly to acquire or distribute. Like the distribution of other goods and services, information distribution relies on the incentives of the distributor. A monopsonist buyer has an incentive to tell farmers about a new technology since they will be able to capture much of the benefit of increased production. A government agricultural extension worker, on the other hand, may lack both the incentive and accountability needed for reliable information supply to meet the needs of smallholder farmers (Anderson and Feder 2007). New research findings suggest approaches to lowering information barriers by improving incentives for those delivering information, reducing the cost of acquiring information, and improving the design of information provision (i.e. content, source, and presentation). Social learning is described in this section, but the externalities associated with information spillovers are discussed in the section on externalities (Section 1). Informational interventions designed to improve market function are described in the sections on input and output market failures (Section 2). Informational inefficiencies may interact with other adoption constraints, making it particularly important to address them simultaneously.

7.1 What is known about informational inefficiencies?

Generally, technologies that are technically complicated, that are very different from the status quo, or that require precise implementation will be prone to information barriers due to low or negative expected profits, especially if used incorrectly. A number of sources of external information are commonly available to the farmer, and the best supplier of information will depend to some extent on the nature of the technology. Sources of information outside of the community are thought to be most valuable at early stages of adoption, as they raise awareness among farmers of the technology option and improve the likelihood of correct use.

Information of a public goods nature—meaning that it can be shared by all and that use by one individual—does not diminish use by others and may be best provided by the public sector. On the other hand, the information associated with market-related goods may be bundled into a sale and is better provided by the private sector (Anderson and Feder 2007).

Agricultural extension has the potential to facilitate technology transfer and management at low cost to the farmer, and can also relay farmer needs back to innovators and policymakers to ensure that innovations meet local needs (Anderson and Feder 2007). Though many farmers cite extension workers as an important source of information (e.g. Weir and Knight 2003), extension is far from realizing its potential in most places (see also Section 2). The information delivered by extension workers may be disconnected from farmer needs, and certain types of farmers may be underserved by extension workers. For example, extension workers may neglect the poorest farmers (Alwang and Siegel 1994), women, and female-headed households (Saito 1994).

The literature on social learning describes information spread as a dynamic process within social networks. In this theoretical framework, farmers learn about the profitability of the technology and about how to correctly use it from their own experience and from their peers' experiences. In many learning models, expected profits increase as information becomes more available, sometimes with negative expected profits from the technology early in the learning process. In the face of negative expected profits and information that is costly to acquire, adoption is unlikely. Whether the farmer's objective is learning the expected yield (Besley and Case 1994; Munshi 2004) or learning the optimal input application (Foster and Rosenzweig 1995; Conley and Udry 2001), the underlying learning process relies on extracting a signal (information) from observed outcomes. Empirical evidence is mixed: adoption by one's peers may make adoption more likely (Foster and Rosenzweig 1995; Conley and Udry 2001; Oster and Thornton 2011), less likely (Kremer and Miguel 2007), or have no effect (Duflo et al. 2008).

While learning from others is important, a number of factors can make social learning inefficient. For example, if individuals rely primarily on family and kinship networks for social learning, then particular subgroups may remain at a low levels of adoption (e.g. Conley and Udry 2010). In addition, the less a farmer is able to observe about the decision process of her peers, the more difficult it may be for her to accurately assess the available information—and the more likely that decisions will be inefficient. Herding outcomes, where every decision maker places too much weight on the decisions of previous decision makers, are an example of inefficient adoption behavior that results from limited information about others' decisions (Banerjee 1992).

Heterogeneity in the characteristics of farmers and plots affect how well farmers are able to learn from one another. Areas with more variable microclimates—or other sources of heterogeneity that affect the benefits of a technology or its proper use—may make learning from the decisions of others more difficult. For example, in India, high-yield varieties of rice are associated with less social learning than high-yield varieties of wheat, which has greater homogeneity in conditions (Munshi 2004). Thus, regions with more varied conditions for agriculture may result in less learning from others. Furthermore if characteristics that affect the profitability of the technology are difficult to observe, then learning from others is more difficult and may not be as accurate as learning from only one's own experience. However, by combining more information sources, social learning is more efficient than individual learning. Restricting peer information sources to a smaller network of more similar individuals makes information about the profitability of a technology or how to use it more informative, but slower to accumulate (Ellison and Fudenberg 1993; Conley and Udry 2001). On the other hand, heterogeneity in characteristics that are easy to observe and are strong determinants of profitability, such as years of schooling, may increase the speed of social learning. This is because it allows individuals to identify others within the network who are likely to provide relevant information for their own adoption decision (Yamauchi 2007).

Both individual and social learning may also be affected by the characteristics of the technology. Technologies that generate unreliable or inconsistent information, such as crops with highly variable outputs or that require specific (and unobservable) growing conditions, will provide less information for a farmer and his or her social network. Technologies that are slow to generate outputs, such as tree crops, may also result in slower learning. Similarly, technologies that offer narrow but potentially important benefits over traditional varieties, such as varieties resistant to a particular pest, may require more time to verify the benefits.

Two recent papers clearly document the frictions that information asymmetries introduce into agricultural markets in developing countries. Hoffmann, Mutiga, Harvey, Milgroom, and Nelson (2012) examine the importance of information asymmetries for the function of agricultural markets using data from Kenya. They find evidence consistent with market failures that lead to higher levels of potentially fatal aflatoxins in maize that is traded than maize that is kept for home consumption. These findings are backed up by a companion paper (Hoffman and Gatobu), which uses an auction to sell maize produced by the buyer (farmer) or by an unknown producer, and find substantially higher willingness to pay for own food. Anagol (2011) also studies the role that adverse selection plays in agricultural markets by studying the cattle market in India. He combines a model of asymmetric information and finds support for predictions that indicate that trades are forgone when information is least available (animals are dry) and that selling is delayed until information can be provided about animal quality. Together, these findings suggest that information asymmetries create substantial frictions to rural agricultural trade. See also Section 2 on input and output market failures.

7.2 What is known about how to overcome informational inefficiencies?

Information is found to improve take-up in settings from agriculture to financial savings, though those who choose to seek out information may be more likely to adopt in the first pace (Madrian and Shea 2002). Simply providing information about the payoffs from a technology has been shown to increase adoption (Jensen 2010), though some studies suggest that information on returns specific to the individual or household is more effective than general information (Jalan and Somanathan 2008). Simpler information may also be easier to process and has been shown to improve adoption outcomes (Rogers 2003; Bertrand et al. 2010). Both the level of specificity and who delivers the information both appear to affect the adoption response. For example, peers may be better able to pass on information about how to use a technology that has sensitive dimensions to its use, as has been seen in the adoption of health products (Oster and Thornton 2011). Miller and Mobarak (2013) find that the decisions of leaders within a community can have a substantial impact on the adoption decisions of others, particularly when a technology is unfamiliar and its benefits are difficult to observe.

Relatively few studies compare the importance of possible sources of information for adoption. In a study of maize farmers in Kenya, Duflo, Kremer, and Robinson (2009) show that intensive extension work significantly increases the use of fertilizers, but other barriers to adoption remain. The effect of external information provision is larger than the impact of just providing materials and giving farmers an opportunity to learn by doing. In the study setting, learning by watching another farmer is as effective as learning by doing, but less effective than intensive extension. The authors do not find strong peer effects: farmers do not learn from their neighbors unless they are explicitly invited to watch a fertilizer trial. Survey evidence on the same farmers suggests that this is due to a lack of communication about the technology. Further work to rank different information sources can improve the cost effectiveness of information delivery programs and determine whether information sources are complements or substitutes.

Recent work suggests that trusted individuals or those perceived to be experts may be in a better position to supply information about the benefits or use of new technologies. Receiving information from a trusted source has been shown to positively affect take-up (Cole et al. 2013). Whether agricultural extension workers are viewed as a trusted source of information is likely to vary across settings, though extension workers may, on average, be less biased than private sector sources of information if the latter are primarily focused on profit (Anderson and Feder 2007). In Tazania, incorporating women into the extension staff was associated with greater access to information by women and appears to have spilled over into greater contact with females by male extension workers (Doss 2001). In the context of an RCT to promote biofortified sweet potato adoption, de Brauw et al. (2011) find that nutritional information retention is better for women who interact with female extension workers. The project targeted information toward women, but surveyed both males and females to explore information diffusion within the household. The authors find that the intervention has no effect on information held by men, while the effect for women is positive and significant. Findings from other sectors show that sensitivity training can make service providers more effective (Bertrand et al. 2004). Extending this into agriculture may indicate that improving the communication skills of extension workers can make them better able to transmit information to women and marginalized farmers.

For new agricultural technologies, information may also be effective in the form of advertising. Advertising is largely about making people feel that they need something and that it is appropriate for them. Advertising is not typically used to target smallholders, presumably due to the lack of profit opportunity for the private sector. Therefore the effectiveness of advertising in these contexts is not well understood. Advertising often targets social identities, which affect perceptions of appropriateness. Presenting products to people in the context in which they are more likely to make the "right" decision may help improve take-up, though no evidence is available on the potential for bundling agricultural decisions. Stigma is often cited as a contributor to low take-up in other contexts (Bertrand et al. 2004). Better understanding of how technologies can overcome stigma and other social norms may help increase adoption rates. Through participation, advertising, and product placement, appropriateness barriers may be overcome by making products more appropriate and by molding individual preferences. The potential for tailoring advertising and targeting to adoption barriers deserves further research.

New psychological research and experience from other sectors suggests that the way information is presented (who provides the information, how much information is given and in what form) can be as important as the content or the source of the information itself. Presenting information in different ways (i.e. framing) can have a large effect on decision making (e.g. Bertrand et al. 2010), though the effects of framing may be less significant than other factors that contribute to expected profits (Cole et al. 2013). Improving approaches to framing and presentation of information, as well as source and delivery, may help overcome information barriers to adoption. Learning may also be enhanced by focusing on psychological factors. Hanna, Mullainathan and Schwartzstein (2012) test a new model of learning that focuses on the importance of overlooked characteristics of the technology – hence "learning through noticing." They provide support for the model in the context of seaweed farmers in Indonesia, which requires attention to many dimensions of production. The authors find that farmers are far from optimal production on dimensions that they are least likely to pay attention to. When provided with explicit information on previously ignored aspects of production, decisions more closely resemble optimal behavior (as defined by the researchers). The paper offers an alternative perspective on the role of information in technology adoption.

Targeting information to the preferences of specific subgroups may also generate more adoption among marginalized populations, though such approaches require further research. For example, some research suggests that exposure to nutritional information is more significant for determining adoption for women than for men (Wendland and Sills 2008). On the other hand, recent work by de Brauw et al. (2011) finds that female-headed households are no more likely to adopt a crop with high nutritional value (orange fleshed sweet potatoes) and households in which more land is controlled by females were slightly less likely to adopt. Finally, bundling technologies with information in ways that increase the salience of the information, such as distributing biofortified seeds to mothers at a health clinic, offers potential to convey a stronger and more memorable message about the health benefits of the technology than distribution through traditional agricultural channels. These approaches have not been tested.

A fundamental challenge to overcoming informational barriers to technology adoption is making information supply and acquisition less costly. New approaches to providing farmers with cheaper means to acquire the information that they need appear promising. For example, listening to agricultural radio programs is associated with fertilizer adoption in Kenya (Wekesa et al. 2003). In Ghana, TradeNet provides SMS-based information for farmers, and delivers price and market information on particular commodities, eliminating middlemen and allowing the market to work more smoothly (World Bank 2008). The e-Choupal program in India is an oft-cited case of providing marketing and technical information through internet kiosks in rural villages. The project has generated productivity and income gains for farmers and eliminated inefficiencies from agricultural markets (Upton and Fuller 2005).[16] While the potential of information and communication technology to lower the costs of access to information appears clear, evidence is still scarce. Both Jensen (2007) and Aker (2010) generate strong evidence that rural agricultural (fish, in the case of Jensen) markets become more efficient following the introduction of mobile phone networks that allow producers to deliver output to the markets where prices are highest. Goyal (2010) also finds that the introduction of free internet kiosks showing daily agricultural information (and the entry of a new corporate buyer) significantly increased average market prices for soybeans in Central India.

Other studies have examined the use of mobile phones to deliver various types of agricultural information. Fafchamps and Minten (2012) test the effect of SMS- based information on agricultural decisions in India and find no significant effect of price and weather information delivered using ICTs. They do find that farmers use the service and attribute decisions to the information received; however, a randomized control group suggests that prevention of crop losses and cropping choices would have been the same in the absence of the technology. They find suggestive evidence that the information has an impact on younger, less experienced farmers. Mitra, Mookherjee, Torero and Visaria (2013) find few results on agricultural production or prices following the introduction of a phone-based information service that provides information to farmers about the prices available in the nearest wholesale market, where the middleman sells the farmer's product.

The Mitra paper explains differences between the Jensen (2007), Aker (2010) and Goyal (2010) findings and the Mitra et al. (2013) and Fafchamps and Minten (2012) findings as a difference in whether the farmer sells to the wholesale market (former set) or to an intermediary (latter set). Svensson and Yanagizawa (2008) is an exception to this summary of the literature. 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.

Other types of information may be more valuable to farmers, and phones or other forms of ICT may lower the costs of delivery. Cole and Fernando (2012) show

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[16] Other examples of the role of information in improving market function are discussed in the section on distribution.

that access to other types of information, specifically to phone-based agricultural consulting services, may have a substantial effect on farmer behavior. They find high demand for the service, and significant changes in take up of a number of agricultural technologies, including high-value, high-risk export crops. The type of information and extension service evaluated here is unique and made feasible by expansions in mobile phone access.

ATAI is supporting a number of new research initiatives to investigate approaches to addressing the lack of information that impedes adoption of beneficial technologies. Two new projects investigate the use of different information technologies to improve the delivery of information to farmers. In Kenya, Kremer, Mullainathan, and Casaburi will explore whether timely SMS messages reminding sugar farmers when fertilizer should be applied, and other best practices, can promote adoption. Further evaluation of the cost-effectiveness of these programs and their impact on adoption will help the design of future interventions. In a pilot project in India, Karlan and co-authors will evaluate a model of using video to disseminate information about agriculture practices. The intervention has the potential to surmount the challenges traditionally facing agricultural extension by offering (1) a participatory process for content production, (2) a locally generated database of how-to videos, (3) human-mediated instruction for dissemination and training.

New ATAI research will also investigate strategies to improve the flow of information between farmers. Also in Kenya, Duflo, Kremer, and Robinson will explore the role of farmer cooperatives as a source of information for their members, and will measure the impact on technology adoption. Magruder and several co-authors will investigate how to optimize the use of pre-existing social networks to disseminate information about and improve adoption of new agricultural technologies. In Malawi, key contact farmers will be incentivized to spread information about new technologies to other farmers within a village.

Conclusion

Further rigorous research on the barriers to agricultural technology adoption and on strategies to help farmers overcome these barriers is key improving agricultural incomes in sub-Saharan Africa and other developing countries. Randomized controlled trials offer benefits over alternative methodologies to investigating impacts. First, they can help avoid the selection bias inherent in self-selection into treatment (adoption) that undermines comparisons of welfare with and without the technology. Second, they can be used to investigate multiple strategies for increasing take-up. Within a single population, strategy A may be compared with strategy B, and both costs and benefits compared directly. Furthermore, proper stratification of farmer characteristics at the randomization stage can provide measures of heterogeneous treatment effects that may be used for better targeting of the technology.

Field experiments that use different treatment conditions to compare interventions aimed at one constraint, another constraint, and both together can help investigate preferred strategies in situations where multiple market failures coexist. For example, in a setting where externalities lower incentives to invest in agricultural practices that adversely affect downstream water quality (Section 1) and where individuals lack clear information about the damages they are causing (Section 7), a research design could offer financial incentives for some villages, provide information to other villages, and do both for a third group of villages. By comparing the behavioral change across these villages, the researchers could observe whether financial incentives are more or less effective when information is also supplied, and could compare the cost effectiveness of the relatively cheap approach of providing information with the more costly approach of financial incentives. Additional systematic research of this type will eventually enhance the ability of governments, donors, and NGOs to provide the interventions needed to help developing country farmers access and benefit from agricultural technologies.

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