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Institutional deficiencies and adoption of farm innovations - Implications and options for agricultural research centers

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Abstract

This paper reviews the conceptual underpinnings and empirical evidence on how poorly functioning institutions serve as constraints to farm innovation. In particular, the paper focuses on imperfections in the land, labor, credit, insurance, and product and factor markets as well as in public extension. Special attention is paid throughout to the role that gender plays in farmer adoption of agricultural technologies. The paper concludes by providing a high level view of the options available to international agricultural research centers to promote diffusion in the difficult environments for which their innovations are destined.

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1. INTRODUCTION

Among the primary objectives of scientists working in the field of agricultural development is to support small farmers in the developing world. This support is provided in the form of improved crop varieties, new techniques to manage pest and disease, and other enhanced farm and crop management practices. Through these innovations, scientists aim to help farmers become more productive, wealthier and better nourished ¬and to do so sustainably. However, the innovations developed by the scientific community do not always diffuse as rapidly or as broadly as predicted by scientists and mathematical models. The reasons why farmers do not adopt agricultural innovations are as varied as the innovations and the farmers themselves. Sometimes, farmers choose not to adopt innovations because of the risk involved, sometimes because they lack the money necessary to invest in the innovation and sometimes simply because they do not know enough about it to make an informed choice. In large part, these constraints are caused by contextual factors which lead to suboptimal outcomes. To put it another way, farmers in developing countries operate in severely constrained environments: credit, insurance, labor and land markets fail to meet their needs; public extension is missing or inadequate; and the conditions of transportation infrastructure leads to crippling inefficiencies in product and factor markets. To achieve their goal of supporting developing country farmers, agricultural scientists need to better understand the nature of these constraints and to develop strategies to reach farmers with potentially life-changing innovations. Such strategies may include working to change the context, adapting the innovations during upstream research or finding the right partners to deliver the innovations despite the severity of contextual constraints.

The remainder of this paper is laid out as follows. First, a conceptual framework is developed providing the necessary background knowledge to understand the economics literature on technology (or innovation) adoption. The primary goal of this section is to provide a basic understanding of key terms and concepts common in the literature and how they are connected. The second section of the paper synthesizes the theoretical and empirical literature which discusses how six major contextual factors lead to adoption constraints. Once the evidence has been laid out, the paper moves on to the implications and options section to discuss three possible approaches for supporting farmers in severely constrained environments. The final section concludes by summing up the main ideas from the other three sections of the paper.

2. CONCEPTUAL FRAMEWORK

Concerns over poverty, food insecurity and degradation of natural resources lead the international community to invest nontrivial sums of money and effort in agricultural research and development (R&D) each year. Much of these resources are directed at improving the lives of farmers in the developing world by delivering innovative solutions to common problems. Generally speaking, these innovations have contributed significantly to improving rural livelihoods and returns to agricultural R&D have been high. However, progress has been uneven and farmers in too many parts of the globe have not benefited. In some cases this is because new technologies and improved management practices have yet to reach them. In many cases, innovations reach farmers but are simply not taken up. Adoption levels which are much lower (and rates much slower) than scientists' *ex ante* predictions has fueled a growing body of research aimed at unraveling the causes. The reasons found in these studies fit into two broad categories. First, disappointing adoption levels for agricultural innovations are due to disappointing innovations. Although an important area of study, this paper is less concerned with deficient innovations and more concerned with the second but closely related category—contextual deficiencies. A contextual deficiency occurs when the environment within which farmers operate mitigates the level and/or rapidity at which they adopt good innovations. The two major causes of contextual deficiencies are absent or poorly functioning institutions and inadequate infrastructure. Following Jack (2011), good innovations (or "technologies") should be understood as those which are successfully adopted by some farmers in some (less constrained) contexts. This is an indication that the innovation is viable and that other factors may be to blame for excessively modest adoption in certain regions.

The six major contextual deficiencies included herein are imperfections in the land, labor, credit, insurance, and product and factor markets as well as in public extension. Such institutional deficiencies lead to six corresponding adoption constraints which are the primary focus of this paper: land, labor, liquidity, risk, input and output, and informational constraints.

There are essentially two avenues through which contextual factors diminish adoption. First, they may lead otherwise effective innovations to become unprofitable. Lack of improved roads, for example, may inhibit market access leading to monopolistic or oligopolistic behaviors by market intermediaries, thus deteriorating the profits farmers are able to obtain by adopting high yielding varieties (HYVs). Second, even when farmers expect net benefits —a necessary adoption condition (see Jack (2011) for discussion of expected profitability) — adoption still may not occur if, for example, lack of financial services leaves farmers unable to obtain necessary capital or insure against risks.

Low levels of adoption translate into lower than anticipated returns on agricultural investment, wasted resources and missed opportunities. Agricultural research centers thus have a responsibility to better understand how the context within which farmers operate is likely to impact adoption of their innovations, and to develop appropriate strategies to promote diffusion. Such strategies may take three forms. First, research centers can advocate for policy-level changes. This may include such things as banking reform, land titling and the building of roads. The second approach which can help ensure development impacts is for research centers to take account of contextual deficiencies during priority setting and or upstream research. An example could be adapting technologies or shifting priorities to better mirror field conditions. The third approach is to develop smart partnerships. For instance, partnering with microcredit organizations may make sense in contexts where farmers are unable to adopt innovations because of binding liquidity constraints. Each approach has its limitations and the appropriate choice will depend on the situation. This theme is further developed in the implications and options section.

2.1. Key terms and concepts

Literature on adoption uses one of two terms when discussing changes in the input-output relationship—"technology" or "innovation", with micro-economists heavily favoring the former. Despite the presence of two distinct terms in the literature, they are often used synonymously. Foster and Rosenzweig (2010), for example, in their overview of the "Microeconomics of

Technology Adoption", define technology generally as "the relationship between inputs and outputs". However, since the current study is intended for a broader audience, and because "technology" may sound narrow and rigid to many scientists, social scientists and policy makers, the present paper will predominately use the term "innovation". Following Sunding and Zilberman (2001), innovation in this paper describes "new methods, customs, or devices used to perform new tasks". This definition is sufficiently broad to include varietal adoption, use of innovative cropping techniques such as integrated pest management (IPM) and use of fertilizers and pesticides. Where the term technology is employed, the same definition applies.

Feder, Just and Zilberman (1985) distinguish between individual (or farm-level) and aggregate adoption of agricultural technologies. The former refers to "the degree of use (by an individual farmer) of a new technology in long-run equilibrium when the farmer has full information about the new technology and its potential" and the latter as "the process of spread of a new technology within a region" —again as measured by the degree of use. In this latter process, the spread of technology can also be thought of as diffusion. Diffusion is dependent on individual farmer adoption which is in turn conditioned by interactions within and among at least three broad categories of factors. The first of these is farm-level factors which include age, gender, farm size, farmer's wealth, bio-physical characteristics of the land, level of education and household size, among others. The second category can be thought of as the context within which farmers make decisions and includes the functioning of markets, the rule of law and the quality of infrastructure. The third category of factors which has been recognized as conditioning adoption relates to the innovation itself —its ease of use, purposes, adaptability and appropriateness. The focus of this paper is the second category, the context, with emphasis on the functioning of markets and the role of transportation infrastructure. The next section introduces the contextual constraints which will lead into the primary discussion of this paper. However, because adoption is finally determined by the interactions among categories of factors, a brief overview of how farm-level factors are believed to influence adoption precedes the discussion of contextual constraints. Interactions with the other category of factors, the characteristics of the innovation, are considered throughout with particular emphasis on the implications for root and tuber crops.

2.2. Overview of farm-level factors influencing adoption

At the farm level, a number of factors are generally recognized as conditioning adoption. The economics literature has historically focused on farm size, asset wealth, human capital (or education), income from off-farm employment, farmer age and, more recently, gender (Sunding and Zilberman, 2001; Feder, Just and Zilberman, 1985; Foster and Rosenzweig, 2010). The relative importance of particular factors (and even the direction of influence) has been difficult to determine empirically, and different studies have yielded conflicting evidence. As the institutional and agro-ecological contexts vary, and as different technologies are studied, the weights attached to particular factors are likely to vary as well. These ambiguities can be exacerbated by measurement difficulties, differing definitions across studies, divergent empirical methods and data reliability issues (see Doss, 2006, for a comprehensive treatment of the challenges faced by micro-level adoption studies). A full examination of how farm-level factors influence farmer adoption is not within the scope of this paper. However, a few observations are called for at this time to inform the later analysis of institutional factors.

Farmer age has an ambiguous relationship to farmer adoption with different studies finding different results depending on the context (Adesina and Baidu-Forson, 1995). The age of the farmer may be negatively correlated with adoption if older farmers are less experimental than younger or more risk averse (*ibid*.). This negative correlation may be heightened for innovations such as conservation practices and ecological methods which often require capital and knowledge investments in the present, but accrue benefits only in the long term. At the same time, more *experienced* farmers may be more likely to adopt agricultural innovations because they are better able to assess the associated risks and benefits.

A large literature has developed around the effects of farmer education on the decision to adopt new technologies and it is generally held that more educated farmers have a higher likelihood of adopting new innovations. Foster and Rosenzweig (2010) summarize three possible reasons for the positive education-adoption relationship as i) a potential wealth effect whereby wealth, not education, is responsible for the increased adoption rate, ii) increased adoption may be the result of increased access to information for more educated farmers or iii) education improves the ability to decode and analyze information, thus better educated farmers are able to assimilate new innovations more efficiently. It is also hypothesized that education increases returns to agricultural technology, thus providing greater adoption incentives. This hypothesis has been tested in numerous studies and a survey by Lockheed, Jamison, and Lau (1980) found that among 37 data sets used in 18 separate studies, 31 show a positive education effect (usually statistically significant) and none demonstrate statistically significant negative returns to education. These results were obtained for formal education and the weighted average increase in returns across all data sets, for which the data could be aggregated, was 7.4 percent for each additional four years of primary education. As Foster and Rosenzweig (2010) point out, not all studies have found education to be important in the adoption decision. Notably, Duflo, Kremer, and Robinson (2008) found that, in the case of fertilizer in Kenya, education did not seem to be a significant adoption determinant. Foster and Rosenzweig (2010) argue that the Duflo et al. (2008) results may be explained by the relatively uncomplicated nature of fertilizer application combined with the fact that this technique had been used in the study area for a considerable length of time before the study took place. In other words, the additional returns to education may be diminished for simple technologies or for those which have been more fully integrated into farming systems over time.

Off-farm income is believed to mitigate the risks of adopting agricultural innovations and hence be positively associated with farmer adoption. This relationship has been confirmed in numerous empirical studies (Marenya and Barrett, 2007; Maertens and Barrett, 2013; Moser and Barrett, 2006). Farm size is also believed to play an important role in adoption, with larger farms having a higher likelihood of adoption. However, farm size may actually be a proxy for other factors which matter for adoption (such as wealth) and thus insignificant if these other factors are controlled for (Feder, Just and Zilberman, 1985). Nevertheless, even controlling for other factors farm size may be important for adoption of capital intensive innovations which are dependent on scale (e.g. tractors). Wealth is also important for adoption and wealthier farmers are typically more likely to adopt new technologies. This may be due to greater access to credit, larger savings and more options for managing risk. It also may be because they have greater access to education and information. Finally, gender is nearly always an important factor in adoption. This is likely a reflection of gender disparities in education and wealth; differential access to information, labor, and credit; membership differences in farmer organizations; and numerous other factors which have implications for adoption.

3. LITERATURE REVIEW: INSTITUTIONAL DEFICIENCIES AND ADOPTION CONSTRAINTS

3.1. The market for credit and liquidity constraints

In theory, farmers ought to adopt profitable innovations in the absence of liquidity constraints (Feder, Just and Zilberman, 1985; Sunding and Zilberman, 2001; Foster and Rosenzweig, 2010). In other words, if they have savings to draw from or are able to borrow, formally or informally, farmers should capitalize on good investment opportunities. However, often farmers, especially low income farmers, lack savings and must rely on the market for credit, and imperfections in the rural credit market are thus problematic from the standpoint of optimal farm investment. Liquidity constraints may be more binding in the case of "lumpy" technologies, such as farm equipment which cannot be adopted incrementally, and of capital intensive technologies; conversely, inexpensive innovations or those which can be adopted incrementally may be less affected. Even when credit is accessible, extremely high interest rates may render investment in innovations unprofitable, particularly investments which have long-term goals such as agro-forestry. In addition, innovations for crops which are typically cultivated for home consumption, such as roots and tubers, may not experience increased adoption even when credit is available if the farmers do not have other sources of income to pay back loans.

Lack of credit may also impact adoption indirectly when insurance markets are missing or ineffectual. When extreme weather causes crop failure or other catastrophic problems befall farmers, consumption may have to be reduced unless there is savings available to draw from. This consumption risk may deter farmers from making optimal investment decisions because of the need to save for the proverbial "rainy day" (Binswanger and Sillers, 1983; Eswaran and Kotwal, 1990). If credit is available to help farmers adapt to a milder consumption, this risk can be covered *ex post* thus enabling farmers to increase their initial investments and experiment with potentially profitable innovations. This issue is further explained in the section on risk and insurance.

Gender is an additional factor which must be considered when discussing liquidity constraints since female farmers often have less access to credit than male farmers (Doss, 2001; Ragasa, 2012). The relationship between access to credit and gender is complex, and multiple possibilities exist as to why women tend to have less access than men. Doss (2001), in her overview of gender and technology in Africa, notes that reduced access may be related to lenders' perceptions of their ability to repay; with farm-size or wealth; or with lower rates of land-titling among women.

Lenders may view women as riskier borrowers if women are perceived as primarily using production for consumption rather than for income generation. At the same time, women tend to have smaller land-holdings and less wealth in relation to men, which may increase the tendency of lenders to see them as risky or, along with lack of land-titles, may mitigate their ability to use collateral to secure capital. In some contexts, there may be additional constraints placed upon women due to prohibitions on entering into legal contracts, lower levels of literacy and financial literacy, and social norms or family responsibilities which hinder women from being involved in financial transactions (Fletschner, 2009; Fletschner and Carter, 2008).

In theory, there are numerous reasons why inaccessible or unaffordable credit may impede adoption, especially by smaller and less wealthy farmers —but does theory hold up to scrutiny? Empirically, liquidity does indeed seem important in farmers' decisions to adopt agricultural innovations and studies in a wide variety of contexts have found evidence that once liquidity constraints are bridged by credit access, farmers choose to try out innovations. Giné and Yang (2009) designed an experiment in which loans were offered to approximately 400 Malawian maize and groundnut farmers[1] for the purchase of high-yielding seed. Among those offered loans, one third accepted, thus providing evidence that liquidity was the salient constraining factor. Interestingly, education, wealth, income, and farm-size were all found to be insignificant in the decision to accept the seed loan. The results from the Giné and Yang (2009) study are in line with an earlier Malawi study by Simtowe and Zeller (2007) which finds credit to be important to both, adoption of hybrid maize and, among credit-constrained households, intensity of adoption. Similar results have been found in empirical studies in northeast Ethiopia for inorganic fertilizer (Beshir, Emana, Kassa and Haji, 2012) and for Chilean potato farmers in the case of modern irrigation methods (Salazar, 2012). Surveys of farmer perceptions in Sierra Leone for improved cassava varieties (Margao, Fornah and Barrie, 2007) and in three districts of Bihar, state in India for potato technologies (Lal, Sinha, Kumar, Pandit and Pandey, 2011) have also found credit access to be an important factor in adoption.

[1] The experiment actually consisted of 800 farmers from 32 districts in Malawi; however, 16 of the groups were offered a loan/insurance combination and 16 were offered just the loan. In this section, only those which were offered the loan (not the loan/insurance package) are considered.

Despite mounting evidence that access to credit is an important ingredient in the adoption of agricultural innovations, a number of questions remains unanswered. In particular, scholars have yet to determine the relationship between credit and risk as it pertains to adoption in different contexts. On that front, the results from a recent study by Karlan, Osei, Osei-Akoto and Udry (2012) (described in more detail in the risk section) provides important insights. Using a three year multi-stage experimental design in which different groups of farmers are randomly selected to receive credit or insurance, Karlan et al. (2012) test which is the salient constraint to increased investment by maize farmers in northern Ghana, liquidity or uninsured risk. They find that while rainfall insurance significantly increases farmers' investments, cash grants (to alleviate liquidity constraints) have at most marginal investment effects. They conclude that uninsured risk is the most important constraint and that if farmers are able to cover such risk they may be able to find the additional resources needed to boost investment in their farms. This implies that even when farmer's liquidity constraints are attenuated, adoption may not occur due to imperfections in the insurance market. It also provides evidence that, at least in some cases, informal risk coping mechanisms are inadequate to raise farm investment even when funds are available.

One possible explanation for the differences in the results of the Karlan et al. (2012) study and the Giné and Yang (2009) study lies in the issue of limited liability. Lenders may not be able to recoup losses from resource poor farmers in the case of a default, providing farmers implicit limited liability. In the Giné and Yang (2009) study, limited liability was explicit in the loan contract. In such cases, the farmer may increase investment because the risk is *de facto* transferred to the lender. In the Karlan et al. (2012) study, the liquidity constraint was solved by the provision of a cash grant rather than a loan. This may have rendered farmers more conservative in their use of the funds since the money (and thus the risk) was truly theirs with no obligation to pay it back or to use it in any particular way. In other words, behavior may vary depending on who is perceived as "owning" the funds and bearing the risk. One last note is that Giné and Yang (2009) looked only at whether farmers used hybrid seeds for that particular season; this may represent only experimentation rather than adoption.

Gender is often discussed as an important factor in agricultural development but there are startlingly few empirical studies testing the effects of women's credit constraints on adoption. Instead, two approaches have been taken which, when combined, provide a better but still incomplete understanding of the issue. First, many econometric analyses of the determinants of adoption include a dummy variable for gender. In the majority of cases it is shown that, even controlling for other factors such as wealth, farm-size, and age, women have lower rates of adoption than men. Several possibilities are discussed as to why this may be the case including differential access to credit, insurance, information and product markets as well as differential participation in farmers' organizations and cooperatives (possibly because of access constraints). Second, a body of literature has begun to emerge examining women's access to credit. A number of findings from these studies are of interest. For instance, using a 1999 dataset of 210 couples in rural Paraguay, Fletschner (2008) finds that women's lack of access to credit in a household where the man does have access is still problematic and acts as a significant drag on household efficiency. In a later study, using the same dataset, she finds evidence that women are more credit constrained than men, that men are not necessarily effective capital intermediates (e.g. even when men have access to credit, women in the same household may still report being constrained), and that women's constraints are generated by a different set of factors than men's (Fletschner, 2009). This latter finding, that different factors are important for men's and women's access to credit, is supported in the results of a study by Mohamed and Temu (2009) over 750 households in 30 villages of rural Zanzibar.

Even knowing that women have lower adoption rates than men, and face more severe credit constraints, the link between credit and adoption is still not quite clear in the case of women. For example, women often have different objectives than men which may include greater household food security rather than income generation. If new innovations are primarily developed to facilitate marketing surplus production, women may demonstrate lower adoption rates even without credit constraints. Similarly, if women are more involved in post-harvest activities and innovations are targeted at earlier stages of production, these innovations may be less appealing to women or perhaps simply less targeted to female farmers. Differential access to information regarding new technologies, or different capabilities to bear production risks, is also possible explanatory factor. That women are more severely and differently credit constrained than men seems clear, but what remains unclear is how precisely this relates to adoption.

Weighing the evidence on credit constraints gives rise to several concluding observations. First, under highly risky conditions, insurance may be more important than credit. This has implications for farmers with fewer options to manage risk and those farming marginal plots which are more sensitive to weather and other aspects of production. Next, limited liability credit can attenuate risk concerns and it might be useful to highlight this feature in credit provision schemes. Last, in the case of an innovation which farmers perceive to be risk-reducing, credit access is likely to improve adoption —especially if the innovation is also capital intensive. In either case, education, marketing and participatory trials may be necessary for farmers to ascertain that a new technology is in fact risk-reducing and such efforts should not ignore differences between men and women. This will be further developed in the section on informational constraints.

3.2. Imperfections in product and factor markets

Product and factor markets are needed to supply complementary inputs and to provide agriculturalists with an outlet for their produce. The functioning of these markets thus has important implications for the adoption of agricultural innovations. Imperfections in input and output markets are caused by absent or poor quality public goods, especially infrastructure, and defective or missing institutions, such as contract enforcement and quality standards. Agricultural policies also influence the functioning of input and output markets, sometimes leading to increased or decreased take-up of agricultural innovations (Sunding and Zilberman, 2001). The adoption-effects of these various factors depend on the characteristics of the technology (for example, the degree to which it requires complementary inputs and precisely which ones), farm-level factors and the characteristics of the crop (such as perishability, bulk and ease of transport, whether it is harvested gradually or all at once and whether it is primarily marketed or consumed on farm). What follows is a discussion of how inadequate infrastructure and institutional deficiencies leads to imperfections in product and factor markets which do not incentivize farm innovation.

The importance of good transportation infrastructure to the host of activities necessary to run a productive and profitable farm can hardly be overstated[2] (Pinstrup-Andersen and Watson II, 2011). Roads facilitate the use of farm inputs by driving down costs, reducing transport time, and improving the consistency and timing of access (Gannon and Liu, 1997). On the input side, crops

[2] For a more comprehensive review of the impacts of infrastructure on agricultural development see Pinstrup-Andersen and Shimokawa (2006) from which much of the discussion in this paper follows. Note, however, that their discussion is of infrastructure in general and also covers sanitation, electrification, irrigation, etc.

which are more dependent on complementary inputs such as fertilizers or pesticides may be more severely affected while on the output side, timing and consistency may be particularly important for perishable or bulky crops which are more difficult to store adequately. Furthermore, cash crops may be more severely impacted by mobility constraints than those produced for home consumption (Pinstrup-Andersen and Shimokawa, 2006). Inadequate transportation infrastructure can lead to market concentration, thereby eroding the power of farmers relative to traders, raising input costs and disincentivizing adoption of potentially productive innovations (*ibid.*). Poor quality or absent roads may also limit the flow of information by limiting interaction with neighboring communities or by making it difficult to access extension services. This in turn has adverse effects on innovation in farming systems. Roads also perform the important function of integrating markets within (and among) nations. When markets are poorly integrated, price signals are weakened, production inefficiencies result and gains from trade are lost. Segmented markets also render farmers more vulnerable to local shocks and lead to more volatile prices. When production is high, local prices decline and farm profits may suffer —particularly if farmers have invested heavily in more expensive inputs such as hybrid seeds, fertilizers, or other innovations. Indirectly, better transportation infrastructure may reduce aggregate risk and increase the attractiveness of lending (*ibid.*), thereby palliating two other major constraints to adoption —risk and liquidity.

Alongside physical infrastructure, governments must also provide the soft infrastructure necessary to facilitate marketing activities. In particular, institutions such as quality standards and contract enforcement have received a lot of attention for their role in creating an enabling environment for agricultural growth and transformation (Pinstrup-Andersen and Watson II, 2011). Contract farming, whereby farmers agree to deliver some portion of their output in exchange for access to important inputs such as credit, seeds and fertilizers, is one way that farmers can overcome adoption constraints. Indeed, some arrangements may even include technology transfer. However, contract enforcement is an essential ingredient to such agreements and where enforcement is lacking, contracting will be a less attractive option. In terms of quality standards, in surveys farmers often cite concerns over adulterated fertilizers and low quality planting materials as a production constraint (Lal, Sinha, Kumar, Pandit and Pandey, 2011; Mbanaso, Agwu, Anyanwu and Asumugha, 2012). This represents another factor which has a disincentivizing effect on the adoption of innovations since either the quality of the innovation itself cannot be guaranteed, or because that of complementary inputs linked to its adoption cannot.

The literature generally agrees that women have less access to agricultural inputs, and imperfections in input and output markets are hence felt differently by female farmers than by their male counterparts (Ragasa, 2012; Fletschner, 2009; Doss, 2001). One reason may be that women generally have lower incomes and are thus more price sensitive. When this is the case, high transportation costs which cause the prices of fertilizers, seeds and other inputs to balloon will be felt more severely by women than by men. This may be exacerbated by imperfections in credit and insurance markets.

Another channel through which imperfections in input and output markets may be amplified for women is mobility. If women are less mobile than men because of social norms of domestic responsibilities, then longer travel times caused by inadequate transportation infrastructure will limit women's access to regional markets where they might purchase needed inputs or market surplus production. This may also affect their access to information, making it less likely that they learn about new innovations and how to use them. Finally, because women often have fewer legal rights than men (*de facto* if not *de jure*), it may be more difficult for them to enter into farm contracts or to take appropriate legal recourse when contracts are not honored.

Empirically, the link between imperfections in input and output markets and the adoption of agricultural innovations is primarily supported by indirect evidence. Empirical work on transportation infrastructure has focused more on the impact of rural roads on broader indicators such as economic growth, consumption, poverty reduction, productivity and output (Dercon, Gilligan, Hoddinott and Woldehanna, 2008; Fan, Hazell and Thorat, 2000; Binswanger, Khandker and Rosenzweig, 1993; Khandker, Bakht and Koolwal, 2009; Zhang and Fan, 2004). In these studies, positive and statistically significant effects are shown, but it is unclear how much of this is a result of more innovative farming systems and how much from other factors. It appears likely that at least part of the increase in output and productivity is due to increased adoption of modern inputs (seeds, agro-chemicals, etc.); however, it is also conceivable that more ideal marketing conditions raise returns to traditional farming activities thus incentivizing additional labor allocation to those activities.

Indirectly, there are at least two reasons to believe that the increased productivity associated with rural road development is a result of more innovative and efficient farming rather than additional labor allocated to traditional farming. First, transaction, and transportation costs are reduced and access to factor and product markets improved by rural roads. Improved market access and reduced transaction costs have been shown to have positive effects on adoption (Zeller, Diagne, and Mataya, 1998). Secondly, a number of studies have shown that one of the main channels through which rural roads lead to increased income and improved poverty outcomes is by generating more off-farm opportunities (Mu and van de Walle, 2011; Escobal and Ponce, 2003). Farm productivity is thus increasing despite receiving a lesser labor share. This is further indirect evidence that rural road improvements do indeed lead farmers to adopt more productive farming methods. However, as will be discussed next, this does not necessarily mean adoption of hybrid seeds, better farm management practices, or implements, but may be primarily due to increased use of fertilizers.

Although there is relatively little evidence directly linking transportation and other infrastructure improvements to the adoption of most farming practices, fertilizer is an exception. Binswanger, Khandker and Rosenzweig (1993) designed a careful study using panel data obtained from India's Additional Rural Income Survey for 85 districts over a 20 year period from 1960/61 through 1980/81. Using fixed-effects frameworks and controlling for agro climatic factors, the authors look at the relationship between infrastructure (roads, electrification, and irrigation) and commercial bank development across districts as well as the relationship between these variables and investment, fertilizer use, and output. They find that roads contribute to increased fertilizer use, though not as much as the presence of commercial banks. In addition, roads make a considerable contribution to increased output, more so than banks, irrigation, electrification or market regulation. They also find that market regulation and especially roads attract commercial banks and thus have an additional indirect impact on intensity of fertilizer use through their attraction of banks and hence credit. These findings are consistent with theory and with the indirect evidence previously mentioned. They are also supported by other empirical studies measuring the relationship between roads and fertilizer use (Manalili and Gonzales, 2005; Zerfu and Larson, 2010).

The focus of the transportation literature has been on the role of roads in linking farmers to distant input and output markets. A less recognized contribution of rural roads is their role in facilitating local market development. A study by Mu and van de Walle (2011) in Vietnam finds that investment in rural roads leads to development of local markets with greater impacts in poorer communities. This suggests that roads not only link farmers to distant markets by reducing transport times and transportation costs, but may actually bring those markets closer to rural communities. Moreover, Mu and van de Walle (2011) find that market development in turn, led to more income diversification as off-farm opportunities increased. There is good evidence linking off-farm income to higher adoption rates, thus roads may have an additional, indirect impact on adoption through off-farm income. However, this is a single study in a single context and broader conclusions must await further study.

To sum up, there is good theoretical evidence that access to product and factor markets matters for adoption of innovations. However, this is still not well understood empirically. While it is clear that roads lead to increased productivity and higher incomes, it is unclear precisely how this occurs. There is compelling indirect evidence that the productivity impact is due to more efficient farming, but the only well-studied mechanism which leads to this efficiency increase is fertilizer use. This provides little insight into adoption of improved varieties, agro-ecological methods, irrigation, integrated pest management and many other important farm innovations. Finally, some of the claims which have strong intuitive appeal —that access to markets is more important in the case of market-oriented crops, that women may have additional mobility constraints that can be solved through better transportation infrastructure, and that roads facilitate the development of seed systems— are supported primarily by qualitative evidence and theory. Rigorous evaluation of such claims is still lacking.

3.3. Labor market imperfections

Farming systems in developing countries often lack mechanization and farm activities are generally labor intensive. Household labor is often insufficient for cultivation, particularly at peak times of the year and for households with larger land-holdings, and hired labor figures prominently in the farming equation[3]. Because of this, several features of rural labor markets are important to our understanding of farmers' cropping decisions, including the decision of whether to adopt a particular agricultural innovation. The adoption literature typically focuses on labor availability, either sourced from the household or hired, and on the relationship between household and hired labor. For the latter focus, the relationship between household and hired labor, the emphasis is on the monitoring problem; hired laborers, especially day laborers, perform farm tasks which are difficult to verify while simultaneously lacking incentives to perform the work well. Household and hired labor are thus imperfect substitutes. This implies the need to monitor which adds to the overall cost of hiring labor. Other important issues include seasonality, labor mobility, and rural-urban and farm-off-farm considerations. These issues and their implications for technology adoption are covered in more detail next.

The labor requirement of an innovation is often understood to be an important determinant of adoption. In a tight labor market, adoption of innovations which increase farms' labor requirements is likely to be constrained (Feder, Just and Zilberman, 1985). Labor scarcity may render it difficult to find additional laborers, especially as more farms begin to adopt, and higher wages, which increase the costs of hiring additional labor, may render the innovation unprofitable. Even when it is possible to hire additional labor and a farmer could expect profits to increase despite the costs, the innovation may still go un-adopted, especially by poorer farmers. The reason for this is discussed earlier in the section on liquidity and credit—additional labor costs must be borne before the crop is marketed and revenue realized. In contrast to labor intensive innovations, labor saving innovations suffer reduced adoption incentives when labor is abundant and inexpensive. This is the case in many rural areas which experience high rates of non-voluntary unemployment.

The discussion above on labor-saving and labor-using innovations is complicated by the issue of labor timing. Farming is characterized by seasonality. In many regions, this entails high labor demand during land preparation and again during harvest and post-harvest processing with lulls and high unemployment during other times. This is particularly true in regions with more

[3] In more technical literature a further distinction is made between casual, or day labor, and permanent labor. Casual labor is usually hired for a day or week at a time to complete a particular task while permanent labor is usually contracted on a seasonal or annual basis and the contract is often renewed. See Ray (1998) for more comprehensive treatment of rural labor markets.

homogeneous cropping patterns, and in such regions seasonal bottlenecks serve as a constraint to the intensity and extent of cultivation. One possible way to alleviate these constraints is to introduce crops which can be planted and harvested at off-peak times. Cassava, for example, can stay in the ground for many months after maturation as well as be harvested piecemeal.

Further complicating matters, some labor-saving technologies actually require additional labor at one time in order to save labor at a later time, resulting in a net savings. An example of this from Bishop-Sambrook (2003) is row planting rather than broadcasting. Broadcasting is faster during planting (when labor constraints are more likely to be binding) but increases the labor required for weeding. However, household labor scarcity combined with liquidity constraints at planting time can mitigate adoption of row planting despite the labor savings later in the season.

The distinction between labor-saving and labor-using innovations and their relationship with adoption is further blurred by gender issues. Although there is a trend toward less differentiation according to gender and there is great variation between regions, women and men are still often responsible for different farming activities (Ragasa, 2012). Changes in the timing of labor requirements may thus have different impacts within a household and are important to consider through a gender lens. For example, a package of innovations which reduces the labor required for land preparation and increases yields may simultaneously increase harvest and post-harvest requirements. In a setting where men are responsible for the former and women the latter, gender obviously becomes an important consideration. Qualitative research in northern Malawi, for instance, found that reincorporation of crop residues, a practice being promoted to enhance soil tilth and fertility, was not initially adopted in the study area because of gender considerations (Msachi, Dakishoni and Kerr, 2009). The practice was perceived as a woman's job and was supposed to occur when women were occupied with other post-harvest activities; it thus went un-adopted until it was later promoted as a man's job. Another example of how adoption may be influenced by gender considerations has to do with wage differentials. If women's wages are lower than men's, then a shift in the labor burden to women may be readily taken up since it frees men to engage in more remunerative wage labor (Doss, 2001). This does not necessarily imply enhanced welfare, at least not for all members of the household. Women are also hindered in their adoption of innovations by the disproportionate time they spend attending to domestic duties (Kerr, 2005), lower average levels of education, and by the fact that they do not always have control over the income they generate (Quisumbing and Pandolfelli, 2010; Kerr, 2005; Msachi et al., 2009)[4].

Just as men and women may have different tasks, so may skilled and unskilled labor. Some tasks, for instance those related to conservation agriculture and integrated pest management (IPM), are relatively sophisticated and even if they do not change the timing or net amount of labor required, they may change the type. A distinction between skilled and unskilled labor may thus be necessary for certain innovations based upon the human capital required to successfully utilize them. However, empirical evidence supporting this distinction remains scant and it is unclear how farm innovations of differing levels of complexity interact with rural labor markets.

Bypassing the previously raised issues and assuming the availability of hired labor to meet new demands placed on farm households as a result of adoption of more labor-intensive cultivation methods, an additional consideration arises —family and hired labor are imperfect substitutes (Frisvold, 1994). The act of hiring and managing laborers generates fixed transaction costs which must be borne by the farm household (Key, Sadoulet and de Janvry, 2000). In other words, buying labor effectively costs more than the wages a laborer receives (Sadoulet, de Janvry and Benjamin, 1996). Farmers wishing to employ laborers must find them (search and screening costs), organize them and monitor their activities (monitoring costs). Inadequate monitoring of hired labor is associated with inefficiency and output losses (Frisvold, 1994). The transaction costs involved with finding labor may increase as a result of inadequate transportation or communication infrastructure, and infrastructure problems may lead to delays for time sensitive planting operations, causing costly losses at harvest time. In addition, time spent managing and monitoring hired labor reduces the amount of time a farmer can spend participating in farming activities[5]. Transaction costs thus serve as a disincentive to hire labor and may mitigate adoption of labor intensive technologies, especially by poorer farmers who are least able to bear the

[4] See also Verma (2001) who explores this theme qualitatively in East Africa and points out that not all women are the same. Certain categories of women (widows, materially poor, younger married women) are more vulnerable and have less control over resources, including their labor.

[5] Two further issues are that monitoring is imperfect and not all tasks are equally verifiable. If adoption or a certain technology requires more labor for less verifiable tasks, its appeal to farmers will probably be less than a technology which increases labor for more easily verifiable tasks (such as weeding).

additional costs and most in need of additional income (Moser and Barrett, 2006; Alwang and Siegel, 1999).

There is ample evidence suggesting that labor availability is an important determinant of technology adoption (Alwang and Siegel, 1999; Moser and Barrett, 2006; Byerlee and Heisey, 1996; Marenya and Barrett, 2007), but the evidence is uneven across conceptual considerations, crops, innovations, and geographic regions. Maize-based systems in Africa are well studied, and to a lesser extent, rice in Asia; however, little of this work looks at transaction costs and the emphasis on rice and maize ignores other important staples such as cassava, potato and sweet potato, as well as fruits and other vegetables. Innovations such as high yield varieties and synthetic fertilizers have received a lot of attention, and somewhat less so various crop management practices, but there is little work on other varietal traits such as early-maturation or drought tolerance. What follows is a brief survey of the empirical evidence on the effects of labor market imperfections on adoption of innovations.

In an early assessment of the impacts of maize research in sub-Saharan Africa, Byerlee and Heisey (1996) argue that peak season bottlenecks are an important consideration, especially for crop management practices such as plant spacing, weeding and multiple rounds of fertilizer application. The impacts of these labor constraints are exacerbated by the higher labor requirement of hybrid maize which makes seasonal labor shortages even more acute. Labor scarcity has been implicated as mitigating take-up of innovative management practices such as SRI in Madagascar (Moser and Barrett, 2006), improved natural resource management in Kenya (Marenya and Barrett, 2007) and soil fertility management practices in southern Africa (Mafongoya, Bationo, Kihara and Waswa, 2006).

The findings of Alwang and Siegel (1999), in the context of maize in Malawi, provide several interesting results which add nuance to the more general findings of Byerlee and Heisey (1996). First, they show that in the absence of liquidity constraints, smaller farms (approximately two hectares or less) with average household labor endowments are able to meet all of their labor demands. However, when liquidity constraints are present, small farmers must sell labor in order to purchase inputs and satisfy immediate consumption needs. This leads them to invest in fewer inputs and to cultivate lower value crops. The average net effect of lower investment is about a ten percent decrease in total income with female headed households being more severely affected. Using a quasi-panel constructed with recall data, Moser and Barrett (2006) observe similar patterns in Madagascar for SRI[6]. Poorer households which are subject to liquidity constraints must sell labor to meet consumption needs, preventing them from adopting an innovation which could potentially double their income. In each of these cases, the 'labor' constraint can be understood in terms of liquidity, and credit may help to facilitate adoption. This implies a close relationship between labor and liquidity, at least in certain contexts.

In recognition of the importance of seasonal labor constraints, attention has recently been focused on labor-saving innovations or those which use off-peak labor as a strategy to overcome obstacles to adoption. In Asia, results of recent work suggest that labor scarcity is one of the primary determinants of adoption of new, labor-saving crop establishment methods (Pandey and Velasco, 2005). Across Asia, labor shortages and high costs have combined with water scarcity to catalyze the adoption of direct seeding and more mechanized planting in rice systems (*ibid.*). Turning back to Africa, Haggblade, Kabwe and Plerhoples (2011) look at conservation agriculture practices among Zambian cotton farmers and found scope for significant income gains without additional capital requirements[7]. This is possible by taking advantage of off-season labor. However, these income gains accrue only when the opportunity cost of labor is relatively low; the better the off-farm opportunities farmers have, the lower the net gain from the additional farming efforts[8]. An additional difficulty may arise if farmers need to earn income in the off-season just to satisfy consumption needs (as in the SRI case discussed above). When this occurs, even low paying off-farm jobs may mitigate adoption.

Another interesting study compares high yielding rice varieties with lower yielding varieties which take advantage of the lower costs of off-season labor. White, Labarta and Leguía (2005)

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[6] Grabowski (2011), in the case of conservation agriculture (CA) in the Angonia highlands of Mozambique, finds evidence which counters that by Moser and Barrett (2006) and Alwang and Seigel (1999). He finds that CA is only feasible for farmers with smaller plots.

[7] They argue gains can be as much as 140 percent by taking advantage of off-season labor lulls for land preparation. This figure can double if capital is available to invest in complementary inputs.

[8] There are two effects occurring as a result of off-farm income. On the one hand, off-farm opportunities may disincentive adoption by creating or exacerbating labor scarcity. On the other hand, off-farm income may help farmers finance new innovations; it also diversifies livelihood strategies and may increase a farmer's ability to bear the risk. Empirically, it is often found that off-farm income increases the likelihood of adoption.

designed a model which accounts for wage differentials based on variations in seasonal labor demand for rice systems in the Peruvian Amazon. In this framework, they are able to obtain results demonstrating that once such differentials are accounted for, the lower yielding variety is more financially viable than the higher yielding variety. The timing of labor requirements can thus be a decisive factor in overall profitability and have important implications for adoption.

3.4. Information imperfections

Farmers have imperfect information about new innovations. They do not know how a new innovation will influence yield; how it might impact the prices they are able to command in product markets (in the case of new crops or varieties); how the innovation interacts with climatic factors (water, heat, cold); and more. These imperfections in information can be costly to remedy and, since farmers are unlikely to use new practices without at least some information about the costs and benefits of doing so, and hence the risk involved, these costs serve as adoption constraints. The degree to which lack of information and the costs of acquiring it mitigate adoption vary based on multiple factors including how different the innovation is from current practices and on specific farm-level attributes (e.g. wealth, land quality and water availability). However, in all cases farmers must know at least something about a new innovation before they will adopt it; and the more they know, the greater the likelihood of adoption[9] (Feder, Just and Zilberman, 1985).

Information is a precursor to adoption and farmers usually receive this information from some combination of the following three sources: learning by doing, learning from the experiences of those within their networks, and learning from outside experts (in the form of public, private or non-profit extension services). Learning rarely, if ever, occurs strictly through one of these sources. Rather, the process is dynamic, consisting of complex interactions among these various sources of information. The appropriate combination varies across innovations, farming systems and types of farmers. Learning from one's neighbors entails low transaction costs and is often the primary way farmers acquire information (Godtland, Sadoulet, de Janvry, Murgai and Ortiz, 2004; Feder, Murgai and Quizon, 2004). By waiting for other farmers to adopt and then learning from

[9] This statement is conditioned, of course, on the appropriateness and profitability of the innovation. In other words, the likeliness of adoption only increases if the farmer is learning positive things about the innovation.

accumulated experience, a farmer can reduce the uncertainty and risk associated with new production practices. This may be an especially important strategy for younger, more inexperienced farmers (Conley and Udry, 2010). However, social learning also has certain drawbacks relative to first-hand experience and extension services. Farm level heterogeneity means that the same factors of production applied to two different plots can have very different outcomes. Furthermore, social learning may provide less accurate information with regards to how these various factors of production were actually employed, thus increasing uncertainty regarding outcomes (Maertens and Barrett, 2013). Additionally, farmers may have relatively small networks, limiting their exposure to innovation; and the information they do obtain, may be too general to be of much use (Conley and Udry, 2001). For these reasons, farmers may prefer to learn from their own experience or from extension experts, especially for more complex or costly practices such as IPM (Feder, Murgai and Quizon, 2004). For such practices, diffusion through farmer to farmer networks may be low or non-existent and more extensive information provision from outsides sources may be necessary (*ibid.*). Information from outside sources is thus an important determinant of farmers' adoption of, and success with, new practices. The focus of this paper is hence on outside sources of information[10], particularly public extension, which are especially important when a technology is newly introduced (Anderson and Feder, 2007) or the practices are more complex or vary significantly from existing practices. The remainder of this section discusses the role of extension in reducing information acquisition costs and hastening the process of discovering and using new technologies to obtain more profit.

Extension comes in a variety of forms, each with distinct philosophies and nuances in overall objectives (Swanson and Rajalahti, 2010). In its simplest form, extension entails the transfer[11] of information regarding production or farm management practices. This transfer may occur in a unidirectional manner from the "expert" to the farmer (as in the old technology transfer paradigm, see Swanson and Rajalahti (2010) for a comprehensive overview), in a bi-directional

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[10] Although this paper focuses on extension, the effects of social learning and the role of networks in the diffusion of information have important implications for choosing appropriate and cost effective extension strategies. For a more thorough review of these issues see Maertens and Barrett (2013), Foster and Rosenzweig (2010), and McNiven and Gilligan (2012).

[11] Note that "transfer" may be too narrow a description of the process. In reality, farmers' indigenous knowledge dynamically interacts with the technical expertise of the extension agent to create essentially new knowledge of how a particular practice or set of practices may interact with one another, as well as with the bio-physical environment. This is especially the case when an explicit objective of extension is to foster mutual learning.

manner which entails mutual learning between farmer and extension agent, or even between farmers with extension agents acting as "knowledge brokers" or facilitators. Claims regarding the effect of each paradigm on the speed, efficiency and effectiveness of farmer learning, and by implication on the timing and likelihood of the adoption of farm innovations, abound; however, empirically assessing extension impacts is inherently difficult and rigorous evaluation of effectiveness and cost efficiency is sparse and results riddled with complications. These difficulties are thoroughly covered by Anderson and Feder (2007). For the purposes of this paper, it is enough to abstract from qualitative differences and focus on a generalized concept of extension as "an important element within the array of market and non-market entities and agents that provide *human capital-enhancing inputs, as well as flows of information* that can improve farmers' and other rural peoples' welfare" (Anderson and Feder (2007), emphasis added).

In the context of informational constraints to the adoption of welfare enhancing production methods, the value of agricultural extension lies in its potential to reduce the transaction costs associated with information acquisition, thereby increasing access and decreasing farmers' level of uncertainty about new innovations. Since larger farms are more able to assume the (fixed) transaction costs of acquiring information, and accrue higher absolute benefits from doing so, they are more likely to experiment with new technologies which entail high fixed transaction costs (Feder, Just and Zilberman, 1985; Feder and Slade, 1984). This implies that for a given level of fixed transaction costs, there may be a farm-size threshold below which farmers will not adopt new technologies. By lowering transaction costs, extension may reduce this minimum farm size. It has also been proposed that the information provided by extension services may serve to reduce a farmer's level of risk-aversion. However, recent empirical results on the last, while not conclusive, show no significant effects from extension (Knight, Weir and Woldehanna, 2003).

In addition to helping relatively poorer farmers overcome what may be insurmountable costs to knowledge acquisition, extension services have the more general effect of accelerating innovation in farming systems. This occurs because of the role of extension in decoding and transmitting new research to farmers (Anderson and Feder, 2007). This can be even more important for less educated farmers since extension may act as a substitute for the schooling which is usually understood as helping farmers decode and assimilate new information (Foster and Rosenzweig, 2010; Anderson and Feder, 2007). In systems where women have lower levels of education, extension may have an enhanced role in helping female farmers to access information about new innovations.

On the gender front, extension has often failed to live up to its expectations. Largely due to the different set of constraints they face, women farmers have different needs than their male counterparts (Swanson and Rajalahti, 2010). Differential access to credit and farm labor, for example, implies the need for extension strategies tailored for women. However, despite their prominent role in agriculture, women are often underserved by extension (Doss, 2001; Doss and Morris, 2001; Swanson and Rajalahti, 2010). This may be related to the fact that most extension workers are men and one strategy which appears to have helped remedy this imbalance in Tanzania is to employ more women extension staff (Doss, 2001).

Empirically, evidence for the role of information in technology adoption has been mixed. Feder, Just and Zilberman (1985) present several possible causes of mixed results, but the central issue is the difficulty in measuring exposure to information. This has led to the use of a number of different proxies—especially education, literacy, and extension visits —some of which probably do not measure what they ought to. Other explanations forwarded by Feder, Just and Zilberman (1985) include factors such as poor extension performance which may have undermined confidence and rendered extension ineffective, and the difficulty associated with understanding the differential effects of information on risk perceptions across farmers and regions. In addition, information exposure is usually measured at a single point in time in the life-cycle of an innovation. If this measurement is taken early on, in the introduction of an innovation, impacts on learning and adoption may appear significant. However, if the study is done many years after an innovation has been introduced, information (as typically measured) may no longer play a substantial role in adoption. This is similar to the argument advanced by Foster and Rosenzweig (2010) to explain the lack of education effects in the Duflo, Kremer and Robinson (2008) study of fertilizer use in Kenya (discussed earlier). Salazar (2012) finds empirical support for this hypothesis in his study of the adoption of two types of irrigation among Chilean potato farmers. Another related difficulty in measuring learning effects is that learning may conceivably increase or decrease adoption depending on whether farmers learn the technology is appropriate for them or not (Foster and Rosenzweig, 2010). Finally, the presence of extension agents is often shown to be correlated with higher adoption rates, but this may not necessarily be the result of learning.

Moser and Barrett (2006), in the context of SRI adoption among Malagasy farmers, found that past extension presence is unrelated to adoption while current presence of extension has a positive and statistically significant impact. They present tentative evidence that these results may be attributable to conformity rather than learning.

Despite the empirical difficulty, there appears to be consensus that information matters and that extension, when properly implemented, can impact both information levels and adoption. For example, Feder, Murgai and Quizon (2004) find modest but statistically significant impacts of Farmer Field Schools (FFS) on knowledge of IPM practices for Indonesian rice farmers. They also find lower levels of pesticide use among FFS participants, indicating that the gains in IPM knowledge were put into practice. In Sierra Leone, surveys have shown that farmers which had contact with the Institute for Agricultural Research (IAR)[12] were far more likely to have adopted various sweet potato and cassava innovations than non-contact farmers (Margao, Fornah and Barrie, 2007). Although not explicitly reported, it can be readily inferred from the data (*ibid.*) that contacted farmers adopted improved varieties at more than double the rate as non-contacted farmers; the difference was approximately six-fold for weed and pest-management practices, probably due to their relative complexity. Regression results from the same study of 280 farmers found that IAR contact was the most significant factor in the adoption of improved varieties — more important than labor availability, land access, gender, and off-farm income among others. Interestingly, this study also found large effects of extension contact on fertilizer use, which is perhaps unexpected since fertilizer is a relatively simple technology to use. The fact that fertilizer use is so low among contacted and non-contacted farmers (28.6 and 7.1 percent, respectively) may indicate that fertilizer is not important in this setting or that there is a general lack of access. Since the authors did nothing to control for other limiting factors such as liquidity constraints or market access, which were indicated in surveys as production constraints, it is unclear if extension impacted fertilizer application through information or simply through access to the technology itself. Given the presence of other constraints (liquidity, fertilizer access, etc.), the latter explanation is perhaps more likely.

[12] The Institute of Agricultural Research appears to have been replaced when the Sierra Leone Agricultural Research Institute (SLARI) was established in 2007.

Barrera, Norton, Alwang and Mauceri (2005), studying the impacts of extension on adoption of IPM practices for potato farmers in Ecuador, also showed strong evidence of learning. Farmers which participated in FFS or in field days had a greater knowledge of various IPM practices and displayed higher levels of adoption than other farmers, even those which were exposed to IPM through contact with FFS participants or pamphlets. Consistent with theory, this study also found that farmers had lower rates of adoption for relatively risky, costly and complex practices. Furthermore, FFS participation appears to be particularly important for the adoption of more complex practices. One last interesting aspect of this study is that the authors explicitly compare the differential effects of different sources of learning. When they include different sources of learning in their model, they find that the source of learning —FFS, field days, learning from FFS participants, pamphlets and learning from non-FFS farmers— is more important than various household effects, including education level.

In a similar context as the Barrera, Norton, Alwang and Mauceri (2005) study discussed above, a rigorous study by Godtland, Sadoulet, de Janvry, Murgai and Ortiz (2004) seeks to measure the effects of FFS participation on IPM knowledge for potato farmers in the Peruvian Andes. They develop a method of scoring knowledge of IPM practices and, using survey data from FFS and non-FFS farmers, empirically test whether extension in the form of FFS effectively transfers knowledge of IPM practices. Their basic findings, which show a 14 percent increase in IPM knowledge scores for FFS participants, are in line with Barrera, Norton, Alwang and Mauceri (2005). However, Godtland, Sadoulet, de Janvry, Murgai and Ortiz (2004) are careful to point out that their study only measures short-term knowledge gains since the surveys were done soon after training. The long-run learning effects thus remain unclear.

Information matters a great deal to adoption and, consistent with theory, it appears even more important for complex practices. Extension has been shown to be an important source of information and regions with strong extension services are likely to see increased and more rapid adoption. Differences in different studies are probably due to errors in measurement and heterogeneity in contexts; they are probably also due to qualitative differences in the provision of extension. This paper primarily reviewed the farmer field school approach and the results may not be generalizable to other forms of extension. Finally, the information effects of extension are only one factor in the adoption equation and may be of secondary importance where farmers face other binding constraints.

3.5. Risk and insurance

There is broad consensus among economists that risk influences farmers' investment decisions, including the decision of whether and to what extent to use new innovations. In particular, the dominant view has been that imperfect insurance markets lead risk-averse households to underinvest in productive technologies. An informal definition of risk aversion is simply that economic agents prefer investments with certain returns over those with uncertain; the more risk-averse an agent is, the more willing to sacrifice income for certainty. The risk that agents are thought to be averse to, in the context of farming, is consumption risk —that is, the risk that income fluctuations will translate into consumption fluctuations. *Consumption smoothing*, or the widely accepted notion that economic agents engage in strategies to spread consumption shocks over time by smoothing out income fluctuations (Morduch, 1995), is thus closely related to risk-aversion. Consumption smoothing strategies can broadly be categorized as *ex post* or *ex ante*. *Ex post* strategies include insurance and borrowing and require appropriate institutions. If households can completely smooth consumption using *ex post* mechanisms, they can effectively behave as if they are risk neutral (Bardhan and Udry, 1999). However, for a number of reasons[13] farmers in developing countries are rarely if ever able to rely solely on ex post strategies and must also make use of *ex ante* ¬strategies. Among these is the tendency to forgo investments in new innovations which is the focus of the current section.

The remainder of this section discusses the relationship between risk and insurance, differential effects of risk on adoption based on farm-level heterogeneity, technology characteristics and gender considerations, and recent challenges to the dominant view as well as possible alternative explanations for how risk influences adoption. Empirical evidence will also be reviewed with particular emphasis on recent studies which shed further light on the complex relationship between risk, uncertainty and the adoption of agricultural innovations. However, before discussing the implications of risk aversion on the adoption of farm innovations, this paper will briefly discuss why rural farmers are unlikely to be perfectly insured.

[13] See Bardhan and Udry (1999) for discussion of why *ex post* strategies, both formal and informal, rarely if ever provide sufficient consumption smoothing.

The need for insurance is attested to by the widespread use of informal mechanisms, such as various community risk-pooling arrangements, gift-giving, and lending, which are evident across the globe. Bardhan and Udry (1999) explain that such informal arrangements can often function in environments where formal insurance would be problematic due to adverse selection and moral hazard. Information, which would be costly to obtain by an outside entity, may be more readily available within close kinship, religious or village networks. This, combined with the ability of such networks to socially sanction non-compliant behavior such as defaulting on obligations, provides important advantages over formal insurance markets. Despite the importance of informal insurance, especially in the case of idiosyncratic risk, informal mechanisms often provide only partial protection. In addition to incomplete coverage of idiosyncratic risks, informal arrangements are ineffective in the case of covariate risks such as climatic fluctuations which affect most or all individuals within a risk-sharing network. This may be particularly true in agricultural contexts dominated by a single crop.

Conceptually, the combination of risk-aversion, imperfect insurance markets and liquidity constraints has important implications for adoption. The implications vary across agricultural innovations, agro-ecological contexts and farms. For instance, factors which increase a crop's riskiness will adversely affect take-up by farmers. Jack (2011) cites a number of examples including crops which are more dependent on outside inputs and thus more vulnerable to intermediaries and imperfections in input markets; highly perishable crops and those which are especially sensitive to the timing and precision of cultivation, storage or marketing activities; crops which experience higher levels of price volatility; and crops which are subject to rigorous quality or safety standards such as export crops. Conversely, characteristics which render a crop or variety less risky such as stable yields, drought tolerance, overall hardiness, disease resistance and qualities which appeal to consumers may increase farmers' propensity to adopt. The same can be said of other risk-reducing innovations such as irrigation and possibly IPM depending on farmer perceptions. At the farm level, risk-increasing factors may include marginal soil quality which renders yields more sensitive to production practices and weather; highly variable and unpredictable rainfall or temperatures; poverty and lack of education; and gender, although women probably face more risks because they tend to be poorer, farm lower quality land and are less-educated. Gender dimensions of risk constraints receive separate treatment in the proceeding section.

Theoretical and empirical evidence suggests that women are more subject to risk constraints than men. Women tend to have less access to financial services, in particular credit and insurance, than men (see section on *Credit constraints*). In part this is due to lower average levels of education and income and in part it is due to cultural and institutional factors bias lenders toward men (Fletschner and Kenney, 2011). Lesser access to risk management instruments implies that women will have lower levels of adoption. In addition, Fletschner and Kenney (2011) cite recent studies which suggest that women are more risk-averse than men and hence less likely to invest in innovations perceived as risky. In regards to this last, there is considerable variation across contexts and the results of such studies must be interpreted with caution (Nelson, 2012; Eckel and Grossman, 2008). Finally, intra-household dynamics may also play a role in mitigating women's adoption of farm innovations since women in some contexts may bear disproportionately the consequences of negative shocks (Quisumbing, Behrman, and Kumar, 2011). However, this is hardly generalizable and shocks in certain contexts may affect women less than men from the same household (*ibid.*).

After more than half century of theoretical work on behavior under risk, and perhaps three decades investigating the effects of risk on farm innovation, econometric evidence that risk induces farmers to engage in less risky activities has been called "thin" (Fafchamps, 2010; Foster and Rosenzweig, 2010; Just, 2007). This is the result of a number of complications involved in measuring the effects of risk on adoption including: the difficulty in obtaining reliable estimates of risk perceptions, problems measuring variation in actual risk between households or individuals, and the related challenge of identifying the effects of risk versus the effects of other factors which are highly correlated with risk (Fafchamps, 2010; Foster and Rosenzweig, 2010). Despite the challenges, a number of studies have sought to provide credible evidence of how risk influences adoption of farm innovations. In particular, recent work using experimental methods has added new, compelling evidence that uninsured risk is an important adoption constraint.

Early work by Rosenzweig and Binswanger (1993) found evidence that uninsured weather risk reduced farm efficiency and income, apparently by inducing farmers to make less risky farm investments. Using ICRISAT panel data from India, the authors estimate the effects of weather variation on farmers' investments in weather-sensitive assets. They found that poorer farmers (those in the bottom quartile of the income distribution) who are subject to greater variation in weather respond by investing in assets which are less affected by weather despite lower returns. This finding did not apply to wealthier farmers, suggesting that wealth may render farmers more willing to take-on risks to achieve higher profits. Presumably this is because access to ex post consumption-smoothing mechanisms (e.g. savings or credit) increases with wealth (Eswaran and Kotwal, 1989). While this study only indirectly relates to adoption since the authors looked at assets generally and not specifically at investments in productive innovations, other studies support the extension of these results to investment in productive assets (Rosenzweig and Wolpin, 1993), crop choices (Dercon, 1996; Kurosaki and Fafchamps, 2002), and input use (Dercon and Christiaensen, 2011).

Several more recent studies also support the notion that farmers may choose to manage risk by lowering investments in productive technologies. In an unpublished conference paper, Salazar (2012) achieves nuanced results which are nevertheless consistent with risk-aversion. Investigating Chilean potato farmers, he finds that production variability and precipitation intensity are important determinants of farmers' adoption of irrigation. However, the effects vary depending on the type of irrigation. As would be expected if farmers are risk-averse and irrigation is perceived as a risk-reducing innovation, the likelihood of irrigation increases with production variance (which is referred to in the study as "risk") and decreases with precipitation intensity. However, among farmers already using traditional irrigation methods (e.g. furrows), adoption of more modern irrigation (e.g. sprinklers) actually declines with production variance. The author argues that this is because modern irrigation is still relatively new and farmers lack sufficient information to judge whether modern methods reduce risk or not. This touches closely upon the dispute over whether farmers are risk-averse or ambiguity-averse, a theme which is considered later in this section.

A recent comprehensive study by Karlan, Osei, Osei-Akoto and Udry (2012) lends compelling evidence that uninsured risk lowers both farmers' investments in their farms and reduces the riskiness of the investments which they do make. In a three-year multi-stage randomized trial in Northern Ghana, they set out to investigate whether liquidity or risk (or both combined) constitute binding constraints to farm investment. Using different designs for each of the three years of the trial, they offered farmers cash grants, rainfall insurance grants, a combination of the two, or the opportunity to purchase insurance at various price levels in different communities. They also included control groups which received neither cash nor insurance. A number of findings from this study are informative. First, they estimate the provision of a cash grant has essentially no influence on total cultivation expenditure while insurance increases cultivation expenditures by $266 (or about 13 percent over the control group) for the season. This effect was even larger for farmers which received both cash and insurance. Next, having insurance appears to shift farmers' investments into relatively riskier activities. Finally, just as theory predicts and as was found in the Rosenzweig and Binswanger (1993) study, the effect is greatest for those on the lower end of the income distribution. Insured farmers at the 25th percentile increase investment by an estimated $95 more than those at the 75th percentile of the distribution. The only investment for which cash alone increased expenditure relative to the control group was fertilizer spending. Based on their results, the authors argue that, at least in their study area, uninsured risk was the salient constraint to increased farmer investment. Similar findings are reported in southwestern China for a randomized trial which measured the effects of insurance on small-holder investment in sows (Cai, Chen, Fang and Zhou, 2009).

The results presented in this section provide strong evidence that risk is in fact an important consideration for farmers deciding how much to invest in their fields. Still, much remains unknown and several areas have been particularly contentious in recent years. In particular, some scholars (Engel Warnick, Escobal and Laszlo, 2011; Barham, Chavas, Fitz, Ríos Salas and Schechter, 2012; Bryan, 2010) have questioned whether risk studies are measuring risk-aversion or ambiguity-aversion. If risk, then it must be assumed that farmers are making decisions based on (subjectively) known probabilities of good versus poor harvests under both, current production practices, and using the new technology. If this is a poor assumption, say because farmers lack sufficient information to assess new innovations, it could be that farmers are actually averse to the unknown prospects of using new practices (as opposed to the loss associated with a poor harvest). This may seem like mere semantics; however, the solution to risk-aversion is to provide insurance, whereas the solution to ambiguity-aversion is to provide information. Certain synthetic facts support an ambiguity-aversion hypothesis while others seem to point to risk-aversion. Studies citing low demand for insurance (Giné and Yang, 2009) appear to indirectly refute risk-aversion —if farmers are risk-averse, we would expect high demand— while recent studies combining lab experiments with econometrics to control for the effects of risk and ambiguity on farmer varietal diversification (Engel Warnick, Escobal and Laszlo, 2011) and on the timing of adoption of genetically modified corn and soy (Barham et al. 2012) appear to offer direct support for ambiguity-aversion. However, as some authors have pointed out, low demand for insurance is not in itself ground to reject risk-aversion. Alternative explanations such as lack of understanding of the product, lack of confidence in the insurer, and liquidity constraints, are also likely possibilities for seemingly low insurance demand (Cole, Giné, Tobacman, Townsend, Topalova and Vickery, 2012; Giné and Yang, 2009). Finally, lab experiments to elicit measures of ambiguity aversion and differentiate it from risk-aversion have still to be refined. Presently, it is unclear how accurately such measures actually represent farmers' behavior, especially out of the lab setting as the stakes increase[14].

Summing up, risk is important in farmers' adoption decisions but empirically difficult to measure. In fact, myriad empirical challenges have plagued work on risk for decades and progress overcoming them has been slow. Still, some things are known with moderate confidence. First, if liquidity is available to help smooth consumption then lacking insurance is less likely to constrain adoption. The implication here is that the less wealthy farmers are probably more constrained by lack of insurance than the wealthy. There is some empirical evidence to support this claim, but more is needed in order to understand the conditions under which this is true and those for which it is not. Given greater risk constraints among relatively low income farmers, it is puzzling that they appear to have lower demand for weather insurance than the wealthy. However, this begins to change as they gain more experience with the product implying that ambiguity aversion may be the culprit, and greater efforts may be necessary to educate less wealthy farmers about the functioning of weather insurance. Second, for many risks, informal types of insurance are probably sufficient. Covariate risks, however, require formal insurance. Where this is not currently available or simply infeasible, other creative strategies need to be developed if diffusion of innovation is to happen broadly and rapidly. To an extent, limited liability credit may help adoption to take place; money back guarantees, warrantees and participatory trials may also help. Third, the distinction between risk and ambiguity aversion is still not well understood. Nevertheless, it stands to reason that risk cannot be understood or assessed without at least

[14] See Just (2007) for discussion of behavioral irregularities in laboratory measures of risk-aversion. It would appear that some farmers are risk-neutral or even risk-loving when the stakes are small but such behavior vanishes as monetary risk increases to non-trivial levels.

some information. Additional information, if appropriately presented to farmers, will hence improve adoption rates. The fourth and final observation is closely connected to the third. Risk-decreasing and risk-increasing innovations are likely to be taken up at different rates depending on the level of risk farmers are already facing. However, because what matters for adoption is farmers' subjective perception of the innovation, education, marketing, and participatory trials, may be necessary to raise awareness of innovations' attributes. Information is thus closely intertwined with risk.

3.6. Land and tenure security

In theory, lack of clearly defined property rights influences farmer investment through three channels: reduced access to credit and higher interest rates, the disincentivizing effect of the fear of expropriation, and uncertainty about the ability to recoup value-enhancing investments through trade (Goldstein and Udry, 2008; Feder and Noronha, 1987; Feder and Feeny, 1991; Besley, 1995). In the case of credit, land is an important element for access since farmers often lack other forms of collateral necessary to overcome imperfections in the credit market caused by information asymmetries. Even if farmers are able to collateralize their land, lack of formal titles may make it more costly for lenders to foreclose in the event of a default. Increased costs are manifested in higher interest rates for farmers. The second channel, fear of expropriation, theoretically leads to lower expected returns. When there is a non-negative probability that a farmer will lose access to a plot of land in the next season, the expected returns to any investment in that plot will be proportionally reduced. Reduced returns mean reduced investment incentives, and we would thus expect lower investment. This argument is more applicable to investments which require one-time fixed capital outlays but have returns which are spread over many years (e.g. irrigation) and investments in long-term soil fertility (e.g. through fallowing). Application of chemical inputs and trial of improved varieties have more immediate returns and would not be subject to reduced incentives unless there is a possibility that land will be expropriated mid-season. Finally, inability to transfer land due to non-exclusive or unclear property rights leads to inefficiencies in the land market and uncertainty on the part of farmers that land-enhancing investments can be recouped. Similar to the fear of expropriation, this is believed to act as a disincentive to certain types of farmer investments.

The theory laid out above is simplified whereas reality is complex. For this reason, a few qualifications are in order. First, formal titling is not always appropriate and formal titles may in some cases be subordinate to existing traditional institutions. Under certain conditions, these traditional institutions are likely to provide sufficient security to incentivize investment. In particular, when land is relatively abundant and communities are small, traditional communal systems may have advantages over formal titling (Feder and Feeny, 1991). However, as population pressure and production intensity increase causing land to become scarce, or new capital intensive innovations become available, more formal titling may be a better option (*ibid.*). This is especially true as agriculture expands into frontier areas which are not covered under existing institutions. Traditional tenure arrangements may also be inefficient when they are overly rigid with regards to land transfer and resource endowments are unevenly distributed (*ibid.*).

A second qualification has to do with the interaction between tenure security and credit. Property rights are theoretically important in helping farmers to access credit. However, property rights may be important determinants of credit access only under narrow conditions. First, holding a land title increases credit access only when lenders require collateral and farmers lack other acceptable forms. Second, titling may only be important in contexts where relatively capital intensive technologies are available and where informal credit is inadequate to purchase them. Finally, titling will not increase investment when other constraints are binding. For example, in contexts where lending institutions are absent, appropriate innovations lacking or product and factor markets are weak, titling is unlikely to increase the flow of credit.

A final observation is that titling appears to be more important for some investments than others. For instance, titling or other forms of secure tenure may be less important for investments which have positive spillovers at a community level and which may be undertaken jointly. Such investments include terracing, canal irrigation, and drainage. Titling is probably also an insignificant factor in farmers' decisions to invest in innovations such as improved varieties and chemical inputs which have immediate benefits and can be adopted incrementally. Conversely, secure tenure (either formal or informal) is likely to be extremely important for long-term investments in the soil —especially fallowing— and at least moderately important for investments which require large capital or labor outlays up front but for which returns accrue over time (e.g. irrigation or tractors).

One of the earliest and most influential studies on property rights and farm investment was that by Feder and Onchan (1987) which tested the effects of formal land ownership on investment and access to credit in three provinces in Thailand. Results from this study overwhelmingly support the theoretical evidence. Farmers lacking property rights in all three provinces included in the study borrowed significantly less than farmers with secure property rights. In two of three provinces the authors also found evidence that more secure property rights led to more capitalization of land while in the third province this was not the case. Informal credit was apparently abundant in the third province and extended on a relational basis rather than through land-collateral; in addition, farmers with secure rights in this province may have used their credit to acquire more land thus reducing ratios of capital to land. Finally, the authors found that possession of a formal title is associated with higher levels of land improvements.

The Feder and Onchan (1987) study was influential in catalyzing empirical scholarship on the relationship between property rights and investment in agricultural systems. However, empirical studies since Feder and Onchan (1987) have yielded mixed results. In some ways, then, the aforementioned study in Thailand may have been a special case. For instance, those farmers in the study lacking formal titles were illegally cultivating national reserve land. Although expropriation was rare, this probably represents a relatively extreme form of tenure insecurity that is not directly comparable to most other regions of interest. Additionally, in many contexts (such as in many parts of Africa) traditional arrangements interact with newer institutions in complex ways which confound easy identification and measurement of tenure security. This was apparently not an issue in the Feder and Onchan (1987) study. In what follows, a more nuanced understanding of how tenure impacts investment is developed based on a review of prominent empirical studies.

Perhaps the most widely cited study investigating the effects of tenure security on farmer investment is that of Besley (1995). In a sample of approximately 300 households in two very different regions in Ghana, Besley (1995) conducts a plot level analysis to understand how possessing transfer rights, influences investment. In one region, he finds strong support that procession of transfer rights significantly increases farmer investment as proxied by tree planting (which is essentially the only investment farmers make in this, a cocoa growing region). His results are robust to a number of different model specifications and, although he is unable to rule out endogeneity[15], he finds strong evidence that endogeneity is not what is driving the results. In the second region, a shallot-growing region where land is predominately leased or rented rather than owned, his results are mixed depending on the specification of the model. The cause of the mixed results may be endogeneity; when an instrument is used for property rights they cease to be a significant determinant of investment. Drawing conclusions from the results of the second region is further complicated because of the small sample size (just over a 100 households) and because some of the investments included in the model (mulching, drainage, making shallot beds, and continuous manuring) are arguably less sensitive to property rights than the tree planting studied in the cocoa growing region.

In a plot level analysis in China, Jacoby, Li and Rozelle (2002) exploit legal prohibitions on land sales and the use of land as collateral to focus explicitly on the effects of expropriation risk on farmer investment in long-term soil health. In the context of their study, local authorities are permitted to reallocate land and occasionally do so. This creates a non-negative probability that land will be expropriated which should theoretically act as a disincentive to investments in the soil that do not have immediate payoffs. Consistent with theory the authors find that, controlling for other important factors, farmers in villages with higher rates of expropriation, invest significantly less in organic fertilizer[16]. Other investments with more immediate returns (e.g. chemical fertilizer) are unaffected by expropriation risk.

Two studies investigating the effects of large scale formal titling programs, one in Peru and one in Vietnam, also provide convincing evidence that property rights matter for investment. Field, Field and Torero (2006) compare adoption of export crops by farm households which received formal

[15] The model is based on the assumption that property rights (or, in this case, transfer rights) are exogenous. More specifically, if the farmer plants trees to improve property rights then property rights are endogenous to the model, implying biased results. Elsewhere in the literature tree planting has been shown to be a strategy to improve tenure security, so, this is a real concern. See Brasselle, Gaspart and Platteau (2002) for further discussion of the endogeneity problem in the context of property rights and investment.

[16] The organic fertilizer used in this context has little nitrogen and is mostly used to maintain soil structure and enhance moisture retention. It is one of the most intensive activities in this farming system taking on average eight percent of total farm labor. Furthermore, the authors argue that the benefits are realized over a period of 4-5 years. These synthetic facts justify considering organic fertilizer a long-term soil investment.

titles under a nation-wide titling program to those which did not. Controlling for regional fixed effects and important household characteristics, they find that title recipients are 68 percent more likely to have begun growing export crops. They do not find any significant effect on credit access and hypothesize the cause to be credit rationing. In a somewhat similar study in Vietnam, Do and Iyer (2008) find evidence that, in the short-term, titling has positive and statistically significant impacts on long-term farm investment; however, the impact is only marginal. The authors reason that in the context of their study, the most likely pathway through which this impact occurred was reduced fear of expropriation. Their findings with regards to credit access mirror those of Field, Field and Torero (2006) —no effect— but they caution against drawing definitive conclusions for two reasons. First, the study takes place shortly after titling and may not capture medium or long-term effects of titling on credit access. Second, the authors note that underdeveloped credit markets may be responsible for the lack of titling effects and point out that land titling is unlikely to catalyze lending without accompanying changes in banking.

In an insightful study, Brasselle, Gaspart and Platteau (2002) argue that the logic of increased tenure security leading to increased investment is problematic in many parts of Africa[17]. They argue that because previous work fails to adequately account for the complex and varied effects of traditional institutions, it misses important nuances in the relationship between tenure and investment. Furthermore, because many studies fail to satisfactorily account for endogeneity, the positive relationship between tenure security and investment may be due to the fact that farmers make investments to increase security or because farmers tend to register land which benefits more from investment. They tested this hypothesis using a dataset of approximately 200 farm households in Burkina Faso and found that investment has a positive effect on tenure security but that the reverse is not true. However, several factors call for caution in extrapolating from these results. First, a narrow set of investments is used including "the delimiting of parcels; the construction of small walls or dams of boulders known as *diguettes* (*filtrantes*) to conserve water

[17] See Place and Hazell (1993) for more mixed evidence from Africa. Although not included in this review, this paper shows a number of mixed findings in Kenya, Rwanda and Ghana which merit consideration and caution against drawing broad conclusions about the applicability of narrow studies. However, this study itself is limited by serious data constraints which render it difficult to judge whether the results were obtained because of these constraints, or because of actual differences across contexts in how investment is affected by tenure security. In the end, the authors claim their results were probably driven by the presence of other binding constraints such as lack of appropriate technologies to invest in and the near complete absence of commercial credit.

and prevent erosion; the plantation of trees; the erection of anti-erosive barriers; and the construction of drains." (*ibid.*). Delimiting of parcels, plantation of trees and possibly construction of small walls may be explicitly intended to improve tenure security whereas, due to positive spillovers, drains and anti-erosive barriers may be less subject to individual security and more influenced by community norms (Jacoby, Li and Rozelle, 2002). Indeed, the authors themselves point out the way that would-be settlers establish themselves on new land is to clear a fallow plot and plant trees; this apparently provides more secure rights than those afforded to households which have long been established in the region. Unfortunately, although the authors point out that agriculture has been intensifying in this area with the result of shorter fallow periods and increased fertilizer use, neither of these investments are included in the regression. Since fallowing is unlikely to improve tenure security (quite the opposite), including it could have increased confidence, in the otherwise narrow results of the study. Finally, the analysis was confined to the household level rather than the plot. If households have varying levels of tenure security on different plots and make investments accordingly, as appears to be the case in Ghana (Goldstein and Udry, 2008), then using the household as the unit of analysis is problematic.

A comprehensive study by Goldstein and Udry (2008) nicely compliments Brasselle, Gaspart and Platteau (2002). In a plot level analysis of intercropped maize-cassava systems in southern Ghana, the authors investigate whether more secure tenure leads to greater investment in long-term soil fertility vis-à-vis fallowing. Similar to Brasselle, Gaspart and Platteau (2002), the authors take a broad view of tenure security which accounts for traditional institutions. However, Goldstein and Udry (2008) take the additional step of exploiting differences in tenure security across plots owned by the same household to assess more accurately the effects of tenure security on investment. They are also careful to rule out plot level characteristics which might drive differential levels of tenure security. Consistent with theory, plots with greater tenure security enjoy higher levels of investment and considerably higher productivity. This is true even for plots owned by a single household. Furthermore, the authors find that men earn approximately 250 percent more per hectare than women. Because the authors have data on various measures of soil quality and plot location, they are able to rule out exogenous differences in plot quality as being responsible for this gap. Also, by looking at differences between plots of men and women in the same household, they are able to control to a large degree for unobservable household characteristics. In the end, the authors argue that fallow duration, which is driven by tenure security, is entirely responsible for this enormous productivity gap. More precisely, conditioned upon fallow duration, men and women from the same household have no statistically significant difference in productivity per hectare.

Synthesizing the empirical evidence, several observations arise regarding the relationship between tenure security and investment. First, tenure security is more important for some investments than for others. At one extreme, fallowing is very sensitive to tenure security while at the other, fertilizer use is at most weakly related to tenure security. Unfortunately, for technologies which lie in the middle of this spectrum there remains little empirical evidence. Still, it is likely that adoption of improved varieties is not directly influenced by tenure security but that adoption of various long-term soil fertility management practices is. Second, where traditional institutions already provide tenure security, formal titles may not be necessary to catalyze innovations. However, in the presence of capital constraints and collateral requirements, the absence of legal titles implies that other strategies are needed to allow farmers access to capital intensive technologies. A corollary to this first observation is that titles are important where other property-right institutions are weak or lacking. This implies that attempts at *ex ante* measurement of property rights using data on formal titling will be biased and of little use in certain contexts. Third, greater tenure security through formal titling only increases the flow of credit under narrow conditions —when lending institutions are present and willing to lend, appropriate and relatively capital intensive innovations are available, and other forms of collateral are lacking. Finally, where women have weaker tenure security than men they may adopt soil-enhancing innovations at lower rates; the extreme case examined in this review is fallowing.

4. IMPLICATIONS AND OPTIONS FOR AGRICULTURAL RESEARCH

As discussed in this paper, numerous factors interact in complex ways to finally determine adoption outcomes and understanding how contextual factors are likely to impact adoption and measuring tradeoffs is a task that can be accomplished imperfectly at best. It is thus a non-trivial undertaking for international agricultural research centers (IARCs) to apply the findings of adoption research. The remainder of this paper discusses the options for IARCs to put into practice the lessons learned by studying constraints to adoption of innovations.

Broadly speaking, there are three possible approaches to allow farmers in constraining environments to benefit from farm innovations: i) adapt the context; ii) adapt the research; iii) adapt the delivery. Generally, the best approach to achieve long-term and sustainable results is to adapt the context. This entails policy changes meant to create an enabling environment for farmers. However, IARCs are not responsible for national policies. Furthermore, national level policy changes may not always be feasible in the short-term. This implies the need to combine policy advocacy with smart innovations and smart partnerships.

As previously noted, changing the context to create enabling environments for small farmers typically represents a “first best” approach. Improvements to the institutional landscape and investments in infrastructure create positive spillovers in other sectors of the economy, leading to a virtuous cycle. The effects of such changes are thus wide-spread and long lasting. Nonetheless, from the perspective of IARCs there are important limitations to this approach. For instance, policy change is often outside the IARCs sphere of influence and IARCs may lack capacity to develop appropriate policies given that many are primarily focused on the physical rather than social sciences. In the time it takes to build such capacity and to develop relationships with national decision-makers, many opportunities will have been missed. Additionally, willing partners may be lacking in certain countries and if the only avenue pursued is macro-level changes, farmers in such nations will be passed over. And even when partners can be mobilized and changes affected, there is no guarantee that future leaders will not reverse course creating an environment of instability. Finally, in some cases the correct institutional configuration is unclear and it may make sense to continue to experiment with solutions on a small scale.

As a complimentary approach to advocating institutional solutions, IARCs also have the option of incorporating on the ground realities into priority setting and upstream research by identifying and adapting R&D investments to meet farmers where they are. Currently, this is perhaps the dominant approach taken by IARCs, though not always incorporating the latest social science research. The chief advantage of this approach is that it can be pursued unilaterally; that is without the need to rely on policy-makers. This implies a certain degree of immunity to policy reversals, as well, as a shorter time horizon before results will be seen. Additionally, upstream course corrections are relatively inexpensive to implement and probably require less in-house capacity building.

Adapting R&D activities to have impacts despite difficult conditions also has its challenges and limitations. First, the context is continually changing, and trying to correct course upstream may be like aiming at a target which is about to move. This problem is compounded by the heterogeneous circumstances of end users. And although this approach may require less in-house capacity building, it does require scientists and managers in IARCs to be informed and up-to-date on the latest social science research. Unless there is commitment at the highest levels within IARCs and among donors, it is unlikely that resources for such training will be made available. Additionally, scientists may lack interest, incentives or time to incorporate lessons from the social sciences into their research. Finally, for innovations which are currently in later stages of development or which have already been completed, it is too late to change course; to help farmers make use of these technologies, IARCs will need to push for policy change or find partners capable of bridging adoption constraints.

Regardless of which approach is used, careful consideration should be given to how best to disseminate the products of agricultural research. However, in the context of poorly functioning or missing institutions finding the proper channel takes on additional importance. Where high quality public goods are available and markets relatively well-functioning, farmers have more freedom to experiment and adapt innovations to suit their needs. Research destined for such environments has a larger margin for error than that directed at low income farmers operating in marginal institutional environments. To reach these farmers, it may be necessary to develop partnerships which specifically address the salient institutional deficiencies. If, for example, uninsured weather risk is the limiting factor, then partners who can offer insurance and provide training to improve financial literacy may be needed to bridge the risk gap and ensure adoption. One advantage of developing smart partnerships is that it may be more flexible, enabling adoption of one innovation in many different contexts despite different constraining factors. This is because such an approach takes advantage of expertise which is already available in the broader development community. Unlike adapting research upstream, taking care in choosing partners can help improve adoption of technologies which have already been developed or which are in later stages of research when it is too late to make changes. This can be accomplished without relying on policy-makers and without burdening scientists; it can also be done more rapidly and with lower levels of investment than either of the other two approaches.

Despite the advantages of using partnerships to bridge the constraints farmers face due to institutional and infrastructural shortcomings, this approach also has serious limitations. Building and maintaining relationships with local partners can be difficult and time-consuming. It entails additional travel and new administrative tasks such as monitoring contracts; it also requires oversight and evaluation. All of these take IARCs further from their traditional role in research and more towards development. The small scale of such an approach provides flexibility, but also means that farmers who are not project participants will not benefit or will do so, only indirectly and maybe only after a significant lag. And because farmers do not operate in a vacuum, bridging their adoption constraints and promoting new innovations on a project-by-project basis may lead to immediate results which are somewhat misleading. If the overall institutional landscape is not simultaneously improved and infrastructure built, the complementary goods and services needed to sustain farmers in the long-run may not emerge. This implies the need for continued intervention and raises sustainability concerns.

5. CONCLUSION

Overall returns to agricultural R&D have been high. However, due to certain barriers, benefits remain unevenly distributed across regions and countries. The most important barriers mitigating farmers' adoption of good innovations emanate from institutional and infrastructural shortcomings. The "first best" solution to reaching farmers in constraining contexts it to change the context; this includes changes to the institutional landscape and investments in infrastructure. Expanding and improving road access is among the most effective means to enhance the functioning of product and factor markets and may have positive spillovers in labor markets while at the same time bettering access to information. Recent work has also emphasized the potential of ICT to bring about some of these same effects. From the perspective of international agricultural research centers (IARCs), contextual change may not be feasible, at least not in the short-run. This implies the need to compliment policy advocacy with smart innovations and smart delivery of research products. Although these two approaches are already being used by IARCs to varying degrees, more need to be done to systematically incorporate the findings from adoption research into upstream R&D and downstream delivery processes. Finally, even while IARCs are working toward augmenting capacity in complimentary approaches, focus should remain on broader changes intended to create enabling environments for farmers. Although this may seem like an impossible task for a single organization, lending support to broader initiatives (e.g. NEPAD or SUN) and working through coalitions and groups of nation-states can help IARCs leverage their resources to maximize long term impacts.

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