AGRICULTURAL ECONOMICS

Agricultural Economics 34 (2006) 207–219

Analyzing technology adoption using microstudies: limitations, challenges, and opportunities for improvement

Cheryl R. Doss*

Yale University, Yale Center for International and Area Studies, New Haven, CT 06520-8206, USA

Received 19 August 2004; received in revised form 25 October 2004; accepted 13 May 2005

Abstract

Policy makers and interest groups have many questions about the use of improved technologies in developing country agriculture. These include the roles of policies, institutions, and infrastructure in the adoption of improved technologies and their impact on productivity and welfare. Most micro-level adoption studies, however, cannot address these important policy issues. Drawing on an extensive review of the literature on the adoption of agricultural technologies, this article suggests alternative approaches for designing technology adoption studies to make them useful for policy makers. It explores the generic limitations of cross-sectional adoption studies carried out in small numbers of communities and discusses some problems faced in conducting such studies. Recommendations include the use of sampling approaches that allow data from microstudies to be generalized to higher levels of aggregation, adherence to clearly defined terms that are standardized across studies, and careful examination of the assumptions that often underlie such studies.

JEL classification: Q16, Q12, O13, O30

Keywords: Agricultural technology; Adoption; Methods of analysis

1. Introduction

For most of the world's poorest countries, agriculture provides the leading source of employment and contributes large fractions of national income. In many of these countries, however, agricultural productivity is extremely low. Clearly, increasing agricultural productivity is critical to economic growth and development.

One important way to increase agricultural productivity is through the introduction of improved agricultural technologies and management systems. National research programs exist in most countries, and working with a network of international centers operating under the auspices of the Consultative Group on International Agricultural Research (CGIAR), these research institutions have developed new agricultural technologies and management practices. A challenge for agricultural researchers is to understand how and when these technologies are used by farmers and with what impacts. For this task, agricultural scientists have turned to social scientists, asking for improved understanding of the mechanisms underlying technology adoption.

Over the years, researchers have worked to answer changing questions about agricultural technology adoption. Initially, policy makers and researchers sought simple descriptive statistics about the use and diffusion of new seed varieties and associated technologies such as fertilizer and irrigation. Concerns arose later about the impact of technology adoption on commodity production, poverty and malnutrition, farm size and input use in agriculture, genetic diversity, and a variety of social issues. Numerous researchers have developed innovative methodologies for addressing such concerns, carried out surveys, and collected enormous amounts of data to describe and document the adoption of new agricultural technologies.

Yet, many questions remain. At the simplest level, we still have considerable gaps in our knowledge of which technologies are being used, where, and by whom. Bigger questions have also arisen. Scholars and policy makers are asking about the roles of policy, institutions, and infrastructure in increasing agricultural productivity. Today, studies of agricultural technology adoption are used widely in four areas of inquiry: assessing the impact of agricultural research;[1] priority setting for research; evaluating the distributional impacts of new technology, including the

*Corresponding author: Tel.: (office) 203-432-9395; fax: 203-432-9886.
E-mail address: Cheryl.Doss@yale.edu (C. R. Doss).

[1] For example, see Evenson and Gollin (2003).

impact on poverty; and identifying and reducing constraints to adoption.

These questions are complex. They require more complicated research methodologies than did the first-generation studies of diffusion. Simple descriptive statistics do not offer much insight into the process of technology adoption or productivity growth. As a result, much of the published literature on technology adoption in recent years has focused on methodological issues, trying to model the process of technology adoption and obtain empirical measures of the importance of different factors. This literature has wrestled with deeply embedded problems of simultaneity and endogeneity.

Too often, however, these methodological advances have not been translated into improved policy-oriented studies that can yield information useful to policy makers. In particular, many studies of technology adoption give disappointingly meager information about the importance of agro-ecological variables and policy environments—and by ignoring these variables, they may give flawed information about the impact of other policies. This article shows that some "adoption studies," by their very design, can give little more than descriptive information. The article also suggests concrete alternative approaches to survey design that can increase the usefulness of the adoption studies that are now widely undertaken. In 1985, Feder et al. reviewed the literature on technology adoption in developing countries in a widely cited article. They concluded that research was needed in five areas: (i) examining the intensity of adoption (not just dichotomous choices); (ii) addressing the simultaneity of adoption of different components of a technology package; (iii) analyzing the impact of incomplete markets and policies on adoption decisions; (iv) contextualizing adoption decisions within social, cultural and institutional environments; and (v) paying attention to dynamic patterns of changes in landholdings and wealth accumulation among early and late adopters. Twenty years later, we have made substantial progress, especially in the first two areas. Yet, some of the concerns raised by Feder et al. (1985) remain unanswered, especially the issues of how institutional and policy environments affect the adoption of new technologies and how the dynamic patterns of adoption affect the distribution of wealth and income.

This article does not seek to retrace or update the ground covered by Feder et al. (1985), which remains a valuable survey of the field.[2] Instead, this article explores current practices in the "technology adoption" literature and asks whether there are simple and feasible steps that can improve not only individual studies but also the collective knowledge that can be gleaned from them. In one sense, this article offers a critique of some common practices; in another sense, it argues that there are potentially important "intellectual public goods" in this literature. While no individual researcher has incentives to provide knowledge that can be combined with information from other studies, our collective knowledge could be advanced much further if we could, as a research community, adhere to some norms for adoption studies. This article is intended to offer some directions and guidelines for those interested in securing "public goods" from future technology adoption studies. It also provides some suggestions for how to answer some of the important and outstanding questions about technologies and productivity among farmers, especially in the poorer countries.

2. Technology adoption: current trends in the literature

The current literature on technology adoption tends to focus on three broad issues. These include: (i) innovative econometric and modeling methodologies to understand adoption decisions, (ii) examinations of the process of learning and social networks in adoption decisions, and (iii) continuing micro-level studies based on local data collection intended to shed light on adoption decisions in particular contexts for policy purposes.

Much of the recent published literature focuses on new methodologies to deal with issues of endogeneity and simultaneity of decisions. Econometric techniques have become increasingly sophisticated in ways that could not have been imagined 20 years ago. Many of the econometric approaches work to compensate for the fact that researchers are generally using cross-sectional data to address issues that are inherently dynamic. Besley and Case (1993) provide a brief review of the empirical approaches in this literature.

One key set of methodological issues is how to address the simultaneity of decision making. Farmers make decisions regarding the sequencing of the adoption components of a package of technology improvements and the intensity of the use of the new technologies. A variety of approaches have been used. Byerlee and de Polanco (1986) demonstrated that farmers adopt improved varieties, fertilizer, and herbicide in a step-wise manner, rather than as a package, in the Mexican *altiplano*. Smale et al. (1995) modeled adoption as three simultaneous choices: the choice of whether to adopt the components of the recommended package, the decision of how to allocate different technologies across the land area, and the decision of how much of some inputs, such as fertilizer, to use. Khanna (2001) used a double selectivity model to look at two site-specific technologies, soil testing, and variable rate technology. The model is designed to compensate for sample selection bias. Dimara and Skuras (2003) modeled the adoption decision as a partial observability process, which allows adoption to be modeled as a two-stage process, even if only one stage is observed. A multivariate approach to look at different technologies that can be adopted in different combinations—improved irrigation techniques and IPM—was used by Dorfman (1996). Pitt and Sumodiningrat (1991) estimated seed-variety-specific profit functions and a metaprofit function that allow for the effect of risk preferences, uncertainty, and schooling on the cultivators' seed variety choice. Their approach incorporates a simultaneous equation of varietal choice and input demand. One study that examines sequential decision making does it explicitly in the

[2] For a recent comprehensive review of the theoretical literature on technology adoption, see Sunding and Zilberman (2001).

context of the potential negative health externalities from micro dams in Ethiopia. In this case, simultaneous adoption of technologies may be infeasible since increasing illness resulting from the dams limits farmers' ability to adopt other productivity enhancing or resource conserving technologies (Ersado et al., 2004).

One of the other issues facing this literature is that it is difficult to compare productivity gains between adopters and nonadopters of technologies, because the adoption decision is correlated with other factors affecting productivity. Barrett et al. (2004) take advantage of the fact that many farmers in Madagascar have introduced an improved rice management technology on some, but not all of their plots. Thus, they can control for productivity differences across plots while holding constant farmer characteristics, including unobserved farmer characteristics.

A second strand of literature focuses on the learning and social networks involved in technology adoption. This broader literature is not necessarily focused on agricultural development, but several papers have used episodes of agricultural technology adoption as examples of social learning. For example, Conley and Udry (2000) modeled the adoption of pineapple production practices in Ghana and found that social learning is important in the spread of the new technologies. Foster and Rosenzweig (1995) found that own experience and neighbors' experiences with high-yielding varieties in India significantly increased the profitability from these varieties. Leathers and Smale (1991) used a Bayesian approach to examine the sequential decisions of adoption among farmers as a learning process; they suggest that farmers adopt a part of the package to learn more about the innovation as a whole. Holloway et al. (2002) used Bayesian spatial probit estimation and found strong positive neighborhood effects with regard to the adoption of high-yielding rice varieties in Bangladesh. Cameron (1999) looked at the impact of learning on the adoption of high-yielding varieties in India, taking advantage of panel data. Munshi (2004) compared wheat and rice growing villages in India to demonstrate that adoption based on observing neighbors is less likely in areas with heterogeneous populations where a farmer may not be able to control for differences in neighbors' characteristics. Using a data set that has measures of individuals' social networks, Bandiera and Rasul (2002) demonstrated that individual networks are important sources of information sharing that affect the adoption decision. They found an inverse-U relationship between the probability that a farmer will grow sunflowers in Mozambique and the number of known adopters in his or her network. Besley and Case (1993) discuss a dynamic multi-agent model of learning and applied it to the diffusion of an improved variety of cotton in India. These studies help us to move beyond the static analyses that look at the characteristics of farmers, plots, and technologies, to understand one aspect of the process of adoption. Only Besley and Case (1993) and Cameron (1999) have access to panel data that allow them to address the dynamic component with data over time on the same farmers. Others infer the processes by looking at cross-sectional data.

Finally, a third strand of literature, aimed primarily at agricultural technology policy, asks about particular technologies and why they are not being adopted in given locations. For example, from 1996 to 1998, the International Center for Wheat and Maize Improvement (CIMMYT) collaborated with national research institutions in East Africa to conduct 22 micro-level studies of technology adoption in Ethiopia, Kenya, Tanzania, and Uganda. These studies looked at the adoption of improved varieties of wheat and maize as well as adoption of chemical fertilizers. They provide useful descriptive information on who is using improved seed and fertilizer in some areas of East Africa.[3] Many similar studies have been conducted across the globe. For example, Mather et al. (2003) examined the adoption of disease resistant bean varieties in Honduras. Hintze et al. (2003) examined the factors, including varietal characteristics, affecting the low levels of adoption of improved maize varieties in Honduras. Ransom et al. (2003) examined the adoption of maize varieties in the hills of Nepal.

Increasingly, attention has shifted from the adoption of new crop varieties to the adoption of new management practices and new crops. For example, Baidu-Forson (1999) examined the adoption of land-enhancing conservation technologies in the Sahel. Shively (1997) and Lapar and Pandey (1999) examined adoption of soil conservation techniques in the Philippines.

Many other studies in this genre are published as working papers, rather than peer-reviewed journal articles, because they do not make a substantial methodological contribution to the field. Although some of these studies make methodological contributions, others contribute primarily by providing information on localized situations of interest to policy makers.

Yet, these three strands of literature are not addressing many of the questions about the dynamics of adoption decisions. In particular, they do not lend themselves to answering the bigger questions of how policy, institutions, markets, and infrastructure affect the adoption of new technologies, and, more important, how these factors interact with new technologies to move farmers out of poverty.

The remainder of this article focuses on how, within all three strands of the literature, we might increase our ability to answer these "big picture" questions and contribute to the intellectual public good. Using new methodologies or econometric techniques cannot resolve the problems if the data are fundamentally inappropriate to the question being asked, or if the questions are not the appropriate ones. Nor do empirical studies help policy makers if they are based on poorly conceived data.

3. What micro-adoption studies can show

Many adoption studies are based on an initial desire to gather basic information about the use of new technologies and to

[3] Many of these studies are referenced throughout this article. For a synthesis of all of the studies, see Doss et al. (2003).

identify constraints to technology adoption and input use. Local governments often need this information for policy making. Microsurveys can provide such information, often at lower expense than full-fledged agricultural censuses.

In addition to generating descriptive data about technology diffusion, microstudies can provide useful background information about the farmers who are currently using a technology and those who are not. For example, relatively little is known at present about the farmers who use modern varieties or fertilizers in the poorest countries. Without basic descriptive information on who is using the technologies and who is not, it is difficult to know how to formulate policies aimed at improving agricultural productivity. Micro-level studies of technology use can document some of this information.

Cross-sectional analysis at the microlevel can answer important questions about technology use. At the most basic level, we can find out what crops (or varieties) farmers are actually growing in their fields and how they are growing them. We can also learn about their decision-making processes by asking farmers about what factors were important to their choices of crops and technologies. Cross-sectional data can also tell us about farmer preferences. We can learn about growing conditions in specific areas and what varietal characteristics are important to farmers. In addition, we can learn about farmers' perceptions of the constraints that they face.

Cross-sectional analysis can also provide some information on patterns of adoption and abandonment. Information on whether or not farmers have ever used improved technologies can be collected, as well as information on what they are currently using. Obviously, these patterns can be more clearly analyzed if we have panel data on farmers over many years, but even a cross-sectional survey can show whether specific technologies have been tried and discarded by farmers, whether they are used intermittently, or whether they have never been tried at all. Farmers are usually able to provide information on why they did not adopt a new technology. Sometimes their answers provide important insights into the constraints facing farmers. Other times, multiple constraints are binding, so that removing the mentioned constraint would not necessarily result in the farmers' adoption of technology.

Information on the profitability of a given technology can sometimes be determined from cross-sectional analysis of micro-level data.[4] Adoption studies typically do not collect data on costs of production, but understanding the conditions under which improved technologies are profitable would add to our understanding of adoption decisions.

Thus, we can obtain a description of the current practices of farmers through micro-level studies. Studies of this kind can explain what farmers are currently doing and may be able to explain what factors influence their decisions. These have important policy implications at the local level, but cannot address the broader policy questions.

[4] Profitability can be difficult to infer, however, from a snapshot at a single moment in time, because of weather shocks and other random events.

4. Limitations of microstudies—generic issues

Microstudies using cross-sectional data can provide important descriptive information on the current use of agricultural technologies by farmers. However, these studies do not—and cannot—address many other important research and policy questions. This section will argue that although some shortcomings of microstudies can be dealt with through careful survey design, some are intrinsic and reflect the fact that these studies are based on data collected at a single point in time. Simply put, there are important questions that cannot be answered with cross-sectional micro-level data, even with advanced econometric tools.

4.1. Lack of dynamics

One fundamental limitation of micro-level adoption studies is that cross-sectional data do not permit analysis of the dynamics of technology adoption. These surveys typically collect cross-sectional data on adopters and nonadopters. Comparisons between the two groups are interesting, but they cannot tell us as much as studies that look at the same farmers before and after they encounter a new technology.[5] Similarly, cross-sectional data cannot tell us much about the impact of a new technology on the well-being of farmers or farm communities—nor on the distributional effects. For example, researchers might like to know the extent to which new technologies have changed the relative and absolute incomes of farmers. But if we only observe adopters and nonadopters, we do not know whether differences in their income or wealth are causes or effects of technology adoption (or both or neither).

To understandthe dynamics of adoption decisions, rather than just developing static descriptions of particular areas, it is necessary to develop panel data sets. Technology adoption decisions are inherently dynamic. Farmers do not simply decide whether or not to permanently adopt an improved variety, but instead they make a series of decisions: whether or not to try planting an improved variety, how much land to allocate to the improved variety, whether or not to continue to grow it, and whether to try a different improved variety. Decisions about other input use and management techniques are at least as complex. Decisions in one period depend critically on decisions made in previous periods. To understand these decisions, farmers' decisions need to be followed over a period of time. This is best done with panel data sets of farmers.[6]

Ideally, we would start to follow farmers before they adopt improved technologies, but panel data studies may be useful even if they are not strictly "before" and "after" studies. Having

[5] It may be possible to collect some retrospective data from farmers, but any retrospective data should be carefully interpreted, since recall and selection biases may be present.

[6] Many software packages, including Stata and Limdep, make it relatively easy to analyze panel data. Useful references on analyzing panel data include Baltagi (2001) and Nerlove (2002).

more than one observation per farmer allows us to control for heterogeneity across households. Since many farmers have already adopted some form of improved technology, we may need to be satisfied with following farmers over time and observing the changing patterns of use of improved technologies. Panel data would allow us to look at changes in the use of improved materials and management practices, both in terms of varietal replacement and the extent of adoption by individual farmers.

Panel data would also help us to understand the distributional impacts of new technology. Since many things change within rural communities, both in response to new agricultural technologies and to changes in outside forces, panel data are needed to sort out the effects. With panel data, we can begin to answer questions such as whether the benefits of being an early adopter continue once many farmers have adopted the technology.

The studies that have used panel data are able to overcome many of these constraints facing cross-sectional analyses. Barham et al. (2004) used the panel aspects of their data on Wisconsin dairy farmers to control for omitted variables and endogenous regressors. They were able to show that nonadopters and adopters differ in important ways and they suggest that nonadopters are unlikely to adopt rBST. In addition, it allowed for distinction between early and late adopters and disadopters. Cameron (1999) compares her panel data results with those based solely on cross-sectional analysis; she finds that "cross-section estimates obtained early in an adoption process, when the new technology is not widely in use and so learning is not widespread, may not be seriously biased by the omission of a learning term. However, the extent to which the inability to control for household heterogeneity in cross-sectional analysis leads to bias is much harder to predict. In this study, although strongly significant, the household fixed effects were not strongly correlated with the explanatory variables (p. 92)."

Because collecting of panel data sets requires a major commitment of time and resources, we should not dismiss the need for cross-sectional analyses of individual sites. Yet, to understand the long-term dynamics of adoption, it is necessary to develop panel data for key locations. Generating the additional information will likely involve considerable expense, but the payoffs could be large in terms of our understanding of technology adoption.

4.2. Lack of variation within samples

A recurring problem with microstudies is that there is no variation across households in a small survey with respect to variables of interest to policy makers. For example, in a survey of a few villages in close proximity to each other, it will be difficult to get much information about the impact of credit or labor market failures. Use of credit and hired labor often depend on the characteristics of both the farmer and the village or region. When all of the respondents live in the same area, there may not be much variation among farmers with respect to market access and infrastructure.

Similarly, agro-ecological factors often influence the adoption of technology. Typically, adoption studies include location variables for the village or region. Studies done in one or two regions often have relatively little agro-ecological variation. Alternatively, where there is agro-ecological variation, location variables will pick up the variation in rainfall, soil quality, and production potential. However, these variables may also pick up variation unrelated to agricultural potential, such as infrastructure and availability of markets for inputs and outputs. Without sufficient variation within the samples, these different relationships cannot be disentangled. It would be useful to have a measure of agricultural potential that shows more variation at the local level—even at the farm level, where possible.

To resolve the lack of variation, there are two options. One is to use considerably larger samples that include variation across the policy, infrastructure, and environment variables of interest. Given that we have already discussed the need for panel data, including much larger samples would greatly increase the cost. The second option is to conduct meta-analyses across different studies to look at the impact of these policy variables.

One recent study that used meta-analysis to examine agricultural technology issues (Pattanayak et al., 2003) analyzed 32 studies of the adoption of agro-forestry practices. They conclude that "credit, savings, prices, market constraints and plot characteristics are potentially important determinants of adoption behavior that have not been studied adequately" (p. 147). Meta-analyses have been used to study related issues. Thiam et al. (2001) used meta-analysis to compare estimates of technical efficiency. They are primarily interested in learning whether the methodology of the individual study affects the results and find that it does. Alston et al. (2000) conducted a meta-analysis of returns to agricultural R&D. They found that the characteristics of the analyst, research, and research evaluation (publication date) all are important. They found no evidence to support the view that the rate of return to research has declined over time. Many challenges face researchers trying to do meta-analyses, whether using formal statistical techniques[7] or simply carefully reviewing the findings in the literature. Boyle et al. (1994), in an analysis of eight contingent-valuation studies of groundwater protection noted: "A major limitation of our meta-analysis is the inconsistent definition of groundwater contamination across studies. This inconsistency limits the variables that we are able to include in the analysis and compromises the interpretations of the variables that we do include in the equations" (p. 1059). This issue of definitions faces meta-analysis of adoption studies as well.

There are a number of ways in which researchers could improve data collection and reporting that would facilitate this type of analysis. They are discussed in detail in the following section.

[7] For a discussion of the Bayesian underpinnings of meta-analysis, see Robert (2001).

5. Opportunities for improvement

As researchers, we can make our studies of technology relevant to policy makers in a number of ways. These opportunities will also help us to address the bigger questions about the dynamic and policy-level factors influencing technology adoption and productivity improvement.

5.1. Defining "adopter"

The first challenge is to clearly define variables that can be compared across different studies. It would be useful for researchers to use similar definitions, where appropriate; at a minimum, variables should be clearly defined in ways that facilitate comparisons.

One key issue that must be addressed is the question of what is meant by an "adopter" of a technology. The definitions of an adopter vary widely across studies, even across the 22 studies that CIMMYT conducted in East Africa examining the adoption of improved varieties of wheat and maize and fertilizer. What exactly is an adopter? This proves to be a complicated question with no obvious 'correct' answer when discussing the adoption of improved varieties.[8] It may be even more difficult to define the adoption of management practices such as those now being promoted for environmental benefits and sustainability.

In defining "adoption," the first thing is to consider whether adoption is a discrete state with binary variables (a farmer either is, or is not, an adopter) or whether adoption is a continuous measure. The appropriateness of each approach may depend on the particular context. Many studies use a simple dichotomous variable approach.[9] For example, a farmer may be defined as an adopter if he or she was found to be growing any improved materials. Thus, a farmer may be classified as an adopter and still grow some local materials. This approach is most appropriate when farmers typically grow either local varieties or improved varieties exclusively (e.g., the adoption of a wholly new crop), or when the management practice is something that cannot be partially implemented. If the interesting aspects of adoption are related to partial adoption (e.g., situations where farmers are increasingly planting more of their land in improved varieties while continuing to grow some local varieties), or to gradual shifts in management practices, then a continuous measure of adoption is more appropriate. Many studies use measures of the proportion of land allocated to new technologies as the measure of adoption.[10] This issue of whether or not to treat adoption as a dichotomous choice was raised by Feder et al. (1985), but it continues to bedevil adoption studies, often because the available data limit analyses in this direction.

Which measure is used may be important. Gebremedhin and Swinton (2003) find that the factors that affect the initial adoption of soil conservation technologies differ from those that affect the intensity of their implementation. Similarly, Weir and Knight (2000) find that household-level education affects the timing of adoption in Ethiopia, but not whether or not household ever adopts new technologies. Often, we seek to understand farmers' partial adoption of new technologies. In an examination of why farmers in Malawi allocate land to a several different maize varieties, Smale et al. (2001b) find that no single explanation—portfolio diversification, safety-first, experimentation, or input fixity—explains the land allocation patterns as well as a model that includes all four explanations. Thus, choosing how to model adoption will depend on the type of technology, the local context, and the research questions being examined.

Defining adoption may be further complicated by the complexity of defining the technology being adopted. Even for the adoption of improved maize and wheat seeds, it is possible to use a variety of definitions. In some cases, farmers were defined as adopters if they were using seeds that had been "recycled" for several generations from hybrid ancestors.[11] In others, adoption was identified with following the extension service recommendations of using only new certified seed (Bisanda et al., 1998; Ouma et al., 2002). Since the definition of adoption encompasses a wide range of dissimilar practices, the results from these studies are not comparable. For management practices, the definitions of adoption may be even more complex. They may include the extent to which farmers use the practice correctly or effectively to gain the full benefits. Studies should explicitly state how they are defining these terms.

In cases in which the full range of farmer behavior is not known *a priori*, it may make sense to ask farmers for detailed information. The researcher can then create an appropriate adoption measure using this detailed data. The researcher might, for example, collapse detailed survey data into an ordered variable (such as whether farmers are using new seed of improved varieties, recycled varieties, or local varieties). This would require the use of multinomial estimation, rather than a simple binary model. We may also want to know whether farmers are growing one improved variety or multiple varieties on their farms. Since many farmers grow more than one variety, measures of the proportion of land planted to improved materials are often used;

[8] It is important to define an adopter not only when it is the dependent variable, but also when it is an independent variable, such as when Brush et al. (1992) examine the impact of the adoption of improved varieties of potato on the genetic diversity of potatoes in the Andes.

[9] For example, Beyene et al. (1998); Hailye et al. (1998); and Salasya et al. (1998).

[10] Including Bisanda et al. (1998); Degu et al. (2000); Gemeda et al. (2001); Kaliba et al. (1998a,b); Katinila et al. (1998); Kotu et al. (2000); Mafuru (1999); Mussei et al. (2001); and Nkonya et al. (1998).

[11] In maize breeding, the genetic integrity of hybrid seeds decays rapidly from one generation to the next. If farmers use hybrid seed in 1 year and then save the seeds to replant in the following year, this is referred to as "recycling" of hybrids. Within a few years, it yields populations that have little genetic relationship to the original hybrid seed—although some traits may be retained. Recycling of maize seed is common in Africa. For example, many farmers in Tanzania had recycled hybrid seeds for 12 years or more (Kaliba et al., 1998b, c; Nkonya, 1998). Whether the use of recycled seed should count as "adoption" is a debatable point and perhaps depends on the context, but it should not be treated as being the same as using new hybrid seed.

this type of measure does not easily lend itself to more than one definition of "improved materials." Collection of detailed data would also allow the creation of measures of adoption that are comparable across studies.

Finally, in defining an adopter, we may sometimes be interested in farmers' histories of technology use. To develop such histories, we must ask not only whether a farmer is currently using a particular technology, but also whether he or she has ever used it. This helps to distinguish farmers who have never tried a technology from those who have tried it and discarded it. In many studies, both categories are treated as "nonadopters," which may conceal important differences.

5.2. Defining policy variables

For many purposes, we may be interested in how incomplete credit, labor, and product markets may affect the adoption of technologies. The challenge is that the measures that we often use do not adequately address the underlying issues. Although econometric techniques may solve some of this, we need to carefully consider the measures that we are using.[12]

5.2.1. Access to credit or cash

Researchers are often interested in whether farmers have access to credit or cash because the lack of such access may constrain farmers from using technologies that require initial investments—whether outlays for seeds and fertilizer at the start of the growing season, large cash expenditures for machinery, investments in infrastructure in fields, or simply added labor. The lack of access to cash or credit is often seen as an indication of market failures that government or NGOs should help to resolve.

Many adoption studies include a variable that is meant to be a measure of credit availability. The best measure would be whether there is a source of credit available to the farmer. This would mean a source of credit for which the farmer is eligible, at a reasonable cost, both in terms of time and money. However, such a measure is often not available. Instead, many studies ask whether or not the farmer *used* credit (Boahene et al., 1999; Negatu and Parikh, 1999) or measure the level of credit use. These measures are problematic. Measures of credit use do not distinguish between farmers who chose not to use available credit and farmers who did not have access to credit. Economic theory tells us that farmers will borrow only if it is profitable to do so—where profitability depends on the price of credit and the potential returns of investment. By contrast, lending institutions will extend credit most readily where they think it is profitable to do so. Conceptually, the distinction between supply and demand for credit is important if we are trying to determine whether credit market failures are important constraints to technology adoption, but in practice it is difficult to disentangle them.

Some creativity can be used to devise an appropriate credit variable. One innovation was to include a measure of whether the farmer had ever received credit (Salasya et al., 1998). This measure still is not perfect, but it is a better measure of access than the simpler question of whether the farmer used credit in the current period. This measure only works if there have not been major changes in the credit availability in the area during the period covered and if farmers have not changed location or material circumstances. Another measure of credit that has been used is the predicted use of credit or the predicted membership in a credit club (Smale et al., 2001a; Zeller et al., 1998). Croppenstedt et al. (2003) use the proportion of farmers in the local area in Ethiopia who bought fertilizer on credit in a given year or paid cash by obtaining a loan from a family or friend.

Ownership of land is often thought to be a prerequisite for obtaining credit. For example, in Ethiopia, farmers must have at least 0.5 ha under maize to participate in the credit scheme for maize. In Kenya, the Seasonal Credit Scheme requires that farmers have at least 5 acres of land. Thus, farmers with smaller amounts of land will not have access to formal credit through these channels. In some circumstances, it may be possible to assume that if any farmer in a village who meets the land requirements obtained credit, then others with similar or greater landholdings also have access to credit. But, it is important to consider both the formal rules and how they are applied in practice.

In a study conducted in Malawi, Diagne and Zeller (2001) tried to obtain information about the potential for credit by asking farmers if they *could* borrow money. This captures farmers' perceptions of whether or not they have access to credit. This perception may be important in determining technology use. However, even here, the availability of credit may depend on its proposed use. For example, farmers may be able to borrow for fertilizer, but not for consumer purchases.

Similarly, if we are concerned about whether the lack of cash is a constraint to the adoption of technology, what we really need to know is whether the farmer has access to a source of cash. Again, there are no obvious measures to use. Income is clearly endogenous to the adoption decision. Yet, it is often included as a right-hand variable (e.g., Boahene et al., 1999). One way in which researchers have tried to resolve this is by asking whether the household has any nonfarm income (Herath and Takeya, 2003). It is expected that this is less related to the adoption decision than farm income; but the choice to have a household member engage in wage labor or nonfarm income-generating activities may be made simultaneously with the decision of which agricultural technology to use. Thirtle et al. (2003) find nonfarm income positive and significant in explaining adoption of GM cotton in KwaZulu-Natal, South Africa. They attribute this finding to both to the farmers' access to cash and to households with nonfarm income being less risk averse. Smale et al. (2001b), use remittances as a measure of exogenous income. While the income of the remitting household

[12] For more details on appropriate variables for use in adoption studies, see Doss (2003).

may not be correlated with technology use in the farm household, the decision of how much to remit may be. One other possible measure is data on local labor markets. Information as to the depth of the labor market would suggest whether or not households could work off-farm to earn funds to invest in agriculture.

In addition, farmers may be able to obtain cash by drawing on savings or selling assets. We would need to know whether the farmer had savings or assets and access to a market in which to sell them. One study on Malawi used the value of maize stocks from last year's harvest as the measure of cash availability (Smale et al., 2001b).

Researchers often believe that limited access to credit or cash is one of the important constraints to technology adoption. Access to cash or credit is difficult to measure, so it is important to be careful in interpreting measures that are trying to capture this effect. Yet, providing credit is one intervention that is relatively straightforward for governments and NGOs to do, so understanding the extent to which lack of credit is a constraint is important.

5.2.2. *Access to information*

Another policy variable that we may be interested in is access to information. Farmers must have information about new technologies before they can consider adopting them. Since extension services are one important means by which farmers gain information on new technologies, variables about extension services are often used as a measure of access to information. As with measures of credit market functioning, what is usually measured is whether a farmer used the extension service. Studies often consider the number of extension visits received by the farmer (Boahene et al., 1999; Herath and Takeya, 2003; Ouma et al., 2002), whether or not the farmer received any extension visits in a particular period (Ransom et al., 2003), or whether the farmer attended a demonstration field day. They also may control for whether the farmer was a contact farmer or hosted an extension field (Ensermu, 1998). Studies may also distinguish between contacts with government extension agents and contact with private firms (Wozniak, 1984). None of these measures captures whether the information was *available* to the farmer; instead, they indicate both whether the information was available though the extension service and whether the farmer took advantage of it. Thus, farmers may have had access to information, but chose not to fully obtain or use it.

More rarely, an effort is made to look at the effectiveness of extension, for example, by measuring whether the farmers are *aware* of the relevant recommendations. This measure actually captures both whether the information resources were available and whether the farmer took effective advantage of them. Thus, it may tell us whether farmers who are aware of the technology and understand it are more likely to use it, but it is not a measure of *access* to information. The simultaneity issues were addressed by Bindlish and Evenson (1997) and they still found that in Burkina Faso, areas with more extension services (measured in staff hours) recorded higher crop yields and that the higher yields were associated with participation in extension contact group activities.

Other approaches have tried to include measures of the farmers' perceptions of the problems and the recommended technologies (e.g., Negatu and Parikh, 1999). For example, Shiferaw and Holden (1998) first model whether or not the farmers recognize land erosion as a problem, before analyzing whether the farmers adopt soil conservation technologies. The literature on learning discussed earlier is relevant to our understanding of access to information. Agricultural researchers often focus on extension, since that is the intervention that government research centers provide. Yet, learning from other sources, such as neighbors, is also important.

Most of these measures of extension and information should not be interpreted as measures of access to information. As with credit, they instead measure the equilibrium levels of information, where the supply of information intersects with the demand for it by farmers, or they may indicate a market failure, but it is not easy to distinguish among these possibilities.

5.2.3. *Access to labor markets*

Other policy variables of interest relate to the availability of labor. Where labor markets do not function effectively, households must supply their own labor for farm activities, so they may choose not to adopt technologies that would require more labor at any specific time, such as land preparation or weeding, than the household can provide. Just as it is hard to measure access to cash or credit, it is difficult to measure a household's access to labor. The measure that is often included is household size, either measured as "all household members," "adult household members," or "adult equivalents." However, all of these measures are influenced by decisions about agricultural production. Household size, especially when we consider extended households, may depend, at least in part, on the productive capabilities of household. For example, Chipande (1987) found an inverse relationship between the number of female-headed households and the agricultural potential in a region of Malawi, suggesting that men remain in households in the rural areas when the returns to agriculture are sufficiently high. If the returns to agriculture are low, some members may migrate to towns in search of employment. Similarly, marriage patterns and the formation of new households depend, in part, on the availability of productive land.

Another approach that is used is to include a dummy variable indicating whether or not hired labor was used on the farm (Ouma et al., 2002). Lapar and Pandey (1999) included a measure of local labor exchange groups to capture the availability of labor. Again, it may be useful to know whether the use of hired labor or labor exchange groups is correlated with the use of improved technologies, but they are clearly endogenous to the decision of which varieties and technologies to use.

We might expect that the availability of labor in local markets would affect agricultural technology use. When there are local labor markets, farmers can hire labor as needed. Members of farmers' households may also sell labor to obtain cash as necessary. The relationship between the local labor market conditions and technology use needs to be explored on a case by case basis. The measures widely used in adoption studies are often not adequate to make policy recommendations about labor markets.

Defining these variables appropriately will allow for greater comparison across studies. In addition, it will allow better interpretation of the results for policy design.

5.3. Representative samples

For microstudies to have broader usefulness, a key issue is to ensure that the samples are appropriately selected. Many studies are located in specific areas, where there is a particular question about technology use. For example, many studies focus on areas where adoption levels were known or expected to be high. Although deliberately targeting these areas is useful as a first step to show that some areas are in fact using improved technologies, it does not explain why some areas had adopted and others had not. This type of survey design and sample selection method raises a number of questions. Although it is valuable to know how farmers are adopting new technologies in the main centers of production, surveys of this kind do not generate much information about aggregate impacts. For this, we need samples that are respresentative so that they can be generalized up to some higher level of aggregation. If new varieties or management practices are encouraging the spread of a crop into new areas, especially into marginal areas, these approaches will not capture it. Nor can we be confident that the studies are providing representative information even at a more microlevel. In fact, some studies specifically acknowledge that the study areas were not representative—for example, when the sites were chosen for ease of access (Beyene et al., 1998; Kotu et al., 2000) or were stratified to include both adopters and nonadopters (Lapar and Pandey, 1999). Thus, they cannot tell us about adoption levels in a broader area.

Ideally, samples should be selected in such a way that generalizations can be made about adoption levels for a country or region—or some other aggregate level, such as an administrative district or an agro-ecological zone. Or they should be selected in such a way that generalizations can be made about groups of farmers—such as large-scale farmers, small-scale farmers, commercial farmers, subsistence farmers, male farmers, or female farmers. This may be done through representative or stratified samples.[13] Using a sample that is representative of only the area currently growing the crop in question is problematic if we are concerned about national-level policy since these areas planted to the particular crop are likely to expand or contract in response to new technologies and policies.

Representative samples will allow the data to be more readily used for impact assessment. There are three major types of impacts that we might be interested in: productivity, poverty and health, and environmental. Most microstudies do not in themselves collect enough data to do impact assessment adequately. Yet, if the data sets are representative, we may be able to use the data in conjunction with data from other sources, to perform some kinds of impact assessment.

5.4. Understanding intrahousehold dynamics

Although the literature on intrahousehold dynamics in agricultural households has grown rapidly in the decades since the paper of Feder et al. was written, very little of the technology adoption literature specifically looks at the dynamics of intrahousehold decision making on the adoption decision.

Usually, the household is modeled as simply having one decision maker. Frequently, it is assumed that the head of the household is the decision maker and the head's characteristics are included in the analysis. Other studies use the characteristics of the farmer, who may or may not be the household head. Frequently, a variable is included for the gender of the household head. However, this confounds the structure of the household with gender, since female-headed households usually include no adult men, while male-headed households may include many adult women. One study that examined whether gender has an effect on the adoption of improved varieties of maize in Ghana found that, controlling for everything else, men and women farmers made the same adoption decisions if they were in male-headed households. However, farmers in female-headed households were less likely to adopt improved varieties. This suggests that female-headed households face constraints not faced by farmers in male-headed households (Doss and Morris, 2001). But there is no evidence to suggest whether this finding holds in other settings. In another study that considers household effects, Asfaw and Admassie (2004) included both the education of the household head and the education of the person with the highest level of education in the household. This assumes that production is enhanced by having someone in the household with more education, even if it is not the head.

But including information on multiple individuals within the household or the household structure is not the same as considering the intrahousehold dynamics of the adoption decision. A growing body of literature suggests that intrahousehold dynamics may be important for agricultural decision making. Udry (1996) found that households in Burkina Faso were less likely to use fertilizer on women's plots than on men's plots, and that total household production could be increased by reallocating fertilizer from men's plots to women's plots. In Cameroon, Jones

[13] In some instances, it may be useful to oversample some areas to obtain enough data on particular regions or farmer categories to be able to obtain statistically significant results about this group. In these cases, the sampling weights should be made available so that it is possible to generalize to a larger scale.

(1983) found that labor was not allocated efficiently across men's rice fields and women's sorghum fields and the explanation that was given is that women were not compensated for the additional labor that they would provide on men's fields. Similarly, in the Gambia rice was a woman's individual crop. The introduction of centralized pump irrigation, which was designed to benefit women, resulted in rice becoming a community crop under the authority of the male compound head (von Braun and Webb, 1989).

We do not yet know how the decision-making processes within households affect the adoption of technologies. One paper that explicitly uses a household bargaining framework to look at technology adoption suggests that a bargaining model of the household does a better job of explaining the adoption of intensive rotational grazing among Wisconsin dairy farmers than conventional models (Zepeda and Castillo, 1997). The authors suggest that this is part of a household strategy to free female labor to work off-farm. In addition, we might expect that men and women have different preferences over technologies and thus, their ability to influence the decision will affect the outcome. This is an area that merits further research.

5.5. Embedding adoption decisions into broader analyses

Finally, it is important for all researchers involved in adoption studies to rethink the implicit assumption behind most adoption studies—namely, the so-called improved technology is better than the existing technologies—and the corresponding policy recommendation that farmers need to be convinced to use these new and better technologies. There is some recognition that farmers face constraints, such as the lack of credit, but implicitly most adoption studies assume that the new technologies are necessarily better.[14]

There are three reasons why farmers do not adopt improved technologies. The first is simply that they are not aware of them—or that they are not aware that the technologies would provide benefits for them. Farmers may also have misconceptions about the costs and benefits of the technologies. The second reason is that the technologies are not available, or not available at the times that they would be needed. The third reason is that the technologies are not profitable, given the complex sets of decisions that farmers are making about how to allocate their land and labor across agricultural and nonagricultural activities. Institutional factors, such as the policy environment, affect the availability of inputs and markets for credit and outputs, and thus, the profitability of a technology.

Simply noting that a farmer has not adopted a "recommended" technology does not necessarily imply that the farmer would be better off if he or she did so. As researchers, we need to understand better the challenges that farmers are facing. We need to focus on the broader issue of how to increase agricultural production—realizing that new technologies may be a key component. Rather than simply asking whether farmers are using improved technologies, we need to be asking them about their levels of production and finding ways to increase it, through improved technologies, improved infrastructure and institutions, and improved policies.

A number of studies are beginning to include measures of technology adoption in studies that look at broader issues of productivity and welfare. For example, Thirtle et al. (2003) examined the impact of the use of Bt cotton in KwaZulu-Natal, South Africa and claim that adopters of the technology benefited. Karanja et al. (2003) examined the potential welfare effects of improved maize technologies; they ask questions about welfare, not simply about whether or not the farmers adopted technologies. Holden and Shiferaw (2004) examined a severely degraded crop-livestock farming system in Ethiopia and include discussion of fertilizer use in their analysis of household welfare. Mahmoud and Shively (2004) examined how IPM technologies affect both crop and technology choices of low-income rice farmers in Bangladesh.

These studies that move beyond simply asking when farmers adopt new technologies to include measures of technology adoption in broader studies of productivity and welfare have the potential to answer some of the broader questions about how to improve the well-being of farmers, especially in poorer countries. These are promising directions, but the opportunities for improvement here will also depend on the quality and appropriateness of the data.

6. Conclusion

Even with one-time cross-sectional studies, with some care it is possible to collect data in such a way that comparisons are possible across study sites and through time. To keep open this possibility, however, it is important to exercise considerable forethought in the design of the surveys. If concepts are defined in similar ways and data are recorded in comparable fashion, the data from disparate microstudies can be combined for various types of meta-analysis. This can be particularly useful for analyzing the "big issues" that cannot be addressed within a single microstudy. For example, no single microstudy can effectively address the impact of government policies or institutions on technology adoption. But a coordinated set of comparable studies might yield information of this kind. If the studies are not designed to be compatible, however, no amount of *ex post* analysis will be able to get at the larger questions.

To keep open the possibility of meta-analysis or synthetic analysis, it is important to pursue some degree of compatibility of definitions and concepts across studies. As noted above, for example, it is important to have comparable definitions of technology adoption—so that we can compare outcomes effectively across different study sites. But this issue is not limited to the definition of adoption.

[14] To understand why farmers do not adopt improved varieties, some work has looked at the varietal characteristics to see if consumer preferences were a limiting factor (Hintze et al., 2003; Smale et al., 1995; 2001a,b).

Consider the question of how the agricultural potential of an area affects adoption. The influence of agricultural potential can be assessed to some extent within individual microsurveys if information is collected from individual farmers on agricultural potential. A more revealing analysis could come from cross-study comparisons, since there is more variation. To make cross-study comparisons, however, we need comparable measures of potential, such as rainfall levels and patterns and soil type and fertility. We need quantitative measures that can be directly compared, rather than simply a qualitative judgment that one study-site has a higher potential than the other. Phrases such as "high potential area" are often used to describe villages in different studies—but the definitions of "high potential" are not easily comparable. A "high potential" maize area in Tanzania may in fact have lower potential than a "moderate potential" site in Kenya.

Next, consider a comparable question about market access. We would expect that areas with higher levels of market access would use more improved technologies, since market access is necessary for purchasing inputs and selling outputs. To examine this, we need to collect information on access to markets for inputs and for outputs. Some of the information needs to be at the level of individual farmers—such as how far they have to go to the nearest local market. In addition, we need to collect information on the distance to the nearest major market. Distance measures should be in miles (or kilometers), time, and cost.

Information on other institutions related to market access might also be useful. In particular, information on credit availability and local labor markets may be needed. For credit, it might be important to know whether there are formal credit facilities and where they are located. In addition, we need to know what the requirements are for farmers to obtain credit. (If the practice differs significantly from the rules, then both should be noted.) In addition, if there are informal sources of credit, including savings and credit associations or moneylenders, this information may also be important. Using this information, it may be possible to gain a sense of whether credit is available to farmers in the area. The extent to which there are functioning local labor markets will affect the ability of farmers to obtain labor and to obtain cash for purchasing other inputs. But these variables must be recorded in some fashion that allows comparison across study sites—and preferably across time.

Similarly, to address questions about the intensification of agriculture and the adoption of technology, it is useful to have compatible measures of land use and population distribution across study sites. Regional measures of population density do not necessarily tell us about the pressure on agricultural land, since not all of the land may be suitable for agricultural production. It may also be useful to have farmers' perceptions on whether there are shortages of land or whether additional land is available to expand agricultural production.

Considering the high cost of primary data collection, it is important that survey data be fully exploited, not only by those who conducted the research, but also by other researchers who may have additional questions and techniques. In order for this to be possible, it is important to document and store survey data in ways that will facilitate their use by others. This includes making the questionnaires, codebooks, and data available. Without documentation, including the specific wording of questions, some of the data are difficult to interpret.

Frequently, the constraint to better adoption studies is the lack of appropriate data, rather than the lack of econometric techniques. With some attention to survey design and data collection, we can greatly improve our understanding of when farmers adopt new technologies and how this contributes to increased agricultural productivity.

Acknowledgments

An earlier version of this article was written for International Center for Wheat and Maize Improvement (CIMMYT), based on an analysis of CIMMYT's adoption studies in East Africa. I gratefully acknowledge the input and suggestions from Wilfred Mwangi, Hugo Verkujl, Hugo de Groote, Michael Morris, Melinda Smale, Mauricio Bellon, Douglas Gollin, Prabhu Pingali, and two anonymous reviewers as well as the work of the many researchers at CIMMYT and national research centers who participated in the local studies. This article was revised while the author was visiting at the Centre for the Study of African Economies, Oxford.

References

Alston, J. M., Marra, M. C., Pardey, P. G., Wyatt, T. J., 2000. Research returns redux: a meta-analysis of the returns to agricultural R&D. Aust. J. Agric. Resour. Econ. 44, 185–215.

Asfaw, A., Admassie, A., 2004. The role of education on the adoption of chemical fertilizer under different socioeconomic environments in Ethiopia. Agric. Econ. 30, 215–228.

Baidu-Forson, J. 1999. Factors influencing adoption of land-enhancing technology in the Sahel: lessons from a case study in Niger. Agric. Econ. 20, 231–239.

Baltagi, B. H., 2001. Econometric Analysis of Panel Data, 2nd ed., John Wiley and Sons, Hoboken, NJ.

Bandiera, O., Rasul, I., 2002. Social networks and technology adoption in Northern Mozambique. CEPR Discussion Paper no. 3341. London, Centre for Economic Policy Research. Available at http://www.cepr.org/pubs/dps/DP3341.asp.

Barham, B. L., Foltz, J. D., Jackson-Smith, D., Moon, S., 2004. The dynamics of agricultural biotechnology adoption: lessons from rBST use in Wisconsin, 1994-2001. Am. J. Agric. Econ. 86(1), 61–72.

Barrett, C. B., Moser, C. M., McHugh, O. V., Barison, J., 2004. Better technology, better plots, or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. Am. J. Agric. Econ. 86(4), 869–888.

Besley, T., Case, A., 1993. Modeling technology adoption in developing countries. Am. Econ. Rev. 83(2), 396–402.

Beyene, H., Verkuijl, H., Mwangi, W., 1998. Farmers' Seed Sources and Management of Bread Wheat in Wolmera Woreda, Ethiopia. Institute of Agricultural Research (IAR now EARO), and International Maize and Wheat Improvement Center (CIMMYT), Mexico, DF, 30 pp.

Bindlish, V., Evenson, R. E., 1997. The impact of T&V extension in Africa: the experience of Kenya and Burkina Faso. The Word Bank Research Observer 12(2), 183–201.

Bisanda, S., Mwangi, W., Verkuijl, H., Moshi, A. J., Anadajayasekeram, P., 1998. Adoption of Maize Production Technologies in Southern Highlands of

Tanzania. International Maize and Wheat Improvement Center (CIMMYT), The United Republic of Tanzania, and The Southern African Centre for Cooperation in Agricultural Research (SACCAR), 38 pp.

Boahene, K., Snijders, T. A. B., Folmer, H., 1999. An integrated socioeconomic analysis of innovation adoption: the case of hybrid cocoa in Ghana. J. Policy Model. 21(2), 167–184.

Boyle, K. J., Poe, G. L., Bergstrom, J. C., 1994. What do we know about groundwater values? Preliminary implications from meta analysis of contingent valuation studies. Am. J. Agric. Econ. 76, 1055–1061.

Brush, S. B., Taylor, J. E., Bellon, M. R., 1992. Technology adoption and biodiversity in Andean potato agriculture. J. Dev. Econ. 39, 365–387.

Byerlee, D., de Polanco, E., 1986. Farmers' stepwise adoption of technological packages: evidence from the Mexican *altiplano*. Am. J. Agric. Econ. 68(3), 519–527.

Cameron, L. A., 1999. The importance of learning in the adoption of high-yielding variety seeds. Am. J. Agric. Econ. 81, 83–94.

Chipande, G. H. R., 1987. Innovation adoption among female headed households: the case of Malawi. Development 18, 315–327.

Conley, T. G., Udry, C. R., 2000. Learning About a New Technology: Pineapple in Ghana. Unpublished Paper. Yale University, Economic Growth Center, Center Discussion Papers, 49 pp.

Croppenstedt, A., Demeke, M., Meschi, M. M., 2003. Technology adoption in the presence of constraints: the case of fertilizer demand in Ethiopia. Rev. Dev. Econ. 7(1), 58–70.

Degu, G., Mwangi, W., Verkuijl, H., Wondimu, A., 2000. An Assessment of the Adoption of Seed and Fertilizer Packages and the Role of Credit in Smallholder Maize Production in Sidama and North Omo Zone, Ethiopia. International Maize and Wheat Improvement Center (CIMMYT) and Ethiopian Agricultural Research Organisation (EARO), Mexico, DF, 24 pp.

Diagne, A., Zeller, M., 2001. Access to Credit and Its Impact on Welfare in Malawi. Research Report 116. International Food Policy Research Institute, Washington, DC, xiii 153 pp.

Dimara, E., Skuras, D., 2003. Adoption of agricultural innovations as a two-stage partial observability process. Agric. Econ. 28, 187–196.

Dorfman, J. H., 1996. Modeling multiple adoption decisions in a joint framework. Am. J. Agric. Econ. 78(2), 547–557.

Doss, C. R., 2003. Understanding Farm Level Technology Adoption: Lessons Learned from CIMMYT's Microsurveys in Eastern Africa. CIMMYT Economics Working Paper 03-07. CIMMYT, Mexico, DF.

Doss, C. R., Morris, M., 2001. How does gender affect the adoption of agricultural innovations? The case of improved maize technology in Ghana. Agric. Econ. 25(1): 27–39.

Doss, C. R., Mwangi, W., Verkuijl, H., DeGroote, H., 2003. Adoption of Maize and Wheat Technologies in Eastern Africa: A Synthesis of the Findings of 22 Case Studies. CIMMYT Economics Working Paper 03-07. CIMMYT, Mexico, DF.

Ensermu, R., Mwangi, W., Verkuijl, H., Hassena, M., Alemayehu, Z., 1998. Farmers Wheat Seed Sources and Seed Management in Chilalo Arwaja, Ethiopia. International Maize and Wheat Improvement Center (CIMMYT) and Ethiopian Agricultural Research Organisation (EARO), Mexico, DF.

Ersado, L., Amacher, G., Alwang, J., 2004. Productivity and land enhancing technologies in Northern Ethiopia: health, public investments, and sequential adoption. Am. J. Agric. Econ. 86(2): 321–331.

Evenson, R. E., Gollin, D., 2003. Assessing the impact of the Green Revolution, 1960 to 2000. Science 300, 758–762.

Feder, G., Just, R. E., Zilberman, D., 1985. Adoption of agricultural innovations in developing countries: a survey. Econ. Dev. Cultural Change 33(2), 255–298.

Foster, A. D., Rosenzweig, M. R., 1995. Learning by doing and learning from others: human capital and technical change in agriculture. J. Political Econ. 103(6), 1176–1209.

Gebremedhin, B., Swinton, S., 2003. Investment in soil conservation in northern Ethiopia: the role of land tenure security and public programs. Agric. Econ. 29, 69–84.

Gemeda, A., Aboma, G., Verkuijl, H., Mwangi, W., 2001. Farmers' Maize Seed Systems in Western Oromia, Ethiopia. International Maize and Wheat Improvement Center (CIMMYT) and Ethiopian Agricultural Research Organization (EARO), Mexico, DF, 32 pp.

Hailye, A., Verkuijl, H., Mwangi, W., Yalew, A., 1998. Farmers' Wheat Seed Sources and Seed Management in Enebssie area, Ethiopia. Institute of Agricultural Research (IAR now EARO), and International Maize and Wheat Improvement Center (CIMMYT), Mexico, DF, 37 pp.

Herath, P. H. M. U., Takeya, H., 2003. Factors determining intercropping by rubber smallholders in Sri Lanka: a logit analysis. Agric. Econ. 29(3), 159–168.

Hintze, L. H., Renkow, M., Sain, G., 2003. Variety characteristics and maize adoption in Honduras. Agric. Econ. 29, 307–317.

Holden, S., Shiferaw, B., 2004. Land degredation, drought and food security in a less-favoured area in the Ethiopian highlands: a bio-economic model with market imperfections. Agric. Econ. 30, 31–49.

Holloway, G., Shankar, B., Rahman, S., 2002. Bayesian spatial probit estimation: a primer and an application to HYV rice adoption. Agric. Econ. 27, 383–402.

Jones, C., 1983. The mobilization of women's labor for cash crop production: a game theoretic approach. Am. J. Agric. Econ. 1049–1054.

Kaliba, A. R. M., Verkuijl, H., Mwangi, W., Mwilawa, A. J. T., Anandajayasekeram, P., Moshi, A. J., 1998a. Adoption of Maize Production Technologies in Central Tanzania. International Maize and Wheat Improvement Center (CIMMYT), The United Republic of Tanzania, and The Southern African Centre for Cooperation in Agricultural Research (SACCAR), Mexico, DF, p. 29.

Kaliba, A. R. M., Verkuijl, H., Mwangi, W., Byamungu, D. A., Anadajayasekeram, P., Moshi, A. J., 1998b. Adoption of Maize Production Technologies in Western Tanzania. International Maize and Wheat Improvement Center (CIMMYT), The United Republic of Tanzania, and The Southern African Centre for Cooperation in Agricultural Research (SACCAR), Mexico, DF, p. 40.

Kaliba, A. R. M., Verkuijl, H., Mwangi, W., Moshi, A., Chilangane, A., Kaswende, J. S., Anadajayasekeram, P., 1998c. Adoption of Maize Production Technologies in Eastern Tanzania. International Maize and Wheat Improvement Center (CIMMYT), The United Republic of Tanzania, and The Southern African Centre for Cooperation in Agricultural Research (SACCAR), Mexico, DF, p. 40.

Karanja, D. D., Renkow, M., Crawford, E. W., 2003. Welfare effects of maize technologies in marginal and high potential regions of Kenya. Agric. Econ. 29, 331–341.

Katinila, R., Verkuijl, H., Mwangi, W., Anadajayasekeram, P., Moshi, A. J., 1998. Adoption of Maize Production Technologies in Southern Tanzania. International Maize and Wheat Improvement Center (CIMMYT), The United Republic of Tanzania, and The Southern African Centre for Cooperation in Agricultural Research (SACCAR), Mexico, DF, 20 pp.

Khanna, M., 2001. Sequential adoption of site-specific technologies and its implications for nitrogen productivity: a double selectivity model. Am. J. Agric. Econ. 83(1), 35–51.

Kotu, B. H., Verkuijl, H., Mwangi, W., Tanner, D., 2000. Adoption of Improved Wheat Technologies in Adaba and Dodola Woredas of the Bale Highlands, Ethiopia. International Maize and Wheat Improvement Center (CIMMYT) and Ethiopian Agricultural Research Organisation (EARO), Mexico, DF, 26 pp.

Lapar, M. L. A., Pandey, S., 1999. Adoption of soil conservation: the case of the Philippine uplands. Agric. Econ. 21, 241–256.

Leathers, H. D., Smale, M., 1991. A Bayesian approach to explaining sequential adoption of components of a technological package. Am. J. Agric. Econ. 73(3), 734–742.

Mafuru, J., Kileo, R., Verkuijl, H., Mwangi, W., Anandajayasekeram, P., Moshi, A. J., 1999. Adoption of Maize Production Technologies in Lake zone of Tanzania. International Maize and Wheat Improvement Center (CIMMYT), the United Republic of Tanzania, and the Southern African Center for Cooperation in Agricultural Research (SACCAR), Mexico, DF, 39 pp.

Mahmoud, C., Shively, G., 2004. Agricultural diversification and integrated pest management in Bangladesh. Agric. Econ. 30, 187–194.

Mather, D. L., Bernsten, R., Rosas, J. C., Viana Ruano, A., Escoto, D., 2003. The impact of bean disease resistance research in Honduras. Agric. Econ. 29, 343–352.

Munshi, K., 2004. Social learning in a heterogenous population: technology diffucsion in the Indian Green Revolution. J. Dev. Econ. 73, 185–213.

Mussei, A., Mwanga, J., Mwangi, W., Verkuijl, H., Mongi, R., Elanga, A., 2001. Adoption of Improved Wheat Technologies by Small-Scale Farmers, Southern Highlands, Tanzania. International Maize and Wheat Improvement Center (CIMMYT) and the United Republic of Tanzania, Mexico, DF, 20 pp.

Negatu, W., Parikh, A., 1999. The impact of perception and other factors on the adoption of agricultural technology in the Moret and Jiru Woreda (district) of Ethiopia. Agric. Econ. 21, 205–216.

Nerlove, M., 2002. Essays in Panel Data Econometrics. Cambridge University Press, New York.

Nkonya, E., Xavery, P., Akonaay, H., Mwangi, W., Anandajayasekeram, P., Verkuijl, H., Martella, D., Moshi, A. J., 1998. Adoption of Maize Production Technologies in Northern Tanzania. International Maize and Wheat Improvement Center (CIMMYT), The United Republic of Tanzania, and The Southern African Centre for Cooperation in Agricultural Research (SACCAR), Mexico, DF, 42 pp.

Ouma, J., Murithi, F., Mwangi, W., Verkuijl, H., Gethi, M., De Groote, H., 2002. Adoption of Seed and Fertiliser Technologies in Embu District, Kenya. Kenya Agricultural Research Institute (KARI) and International Maize and Wheat Improvement Center (CIMMYT), Mexico, DF.

Pattanayak, S. K., Mercer, D., Sills, E., Yang, J., 2003. Taking stock of agroforestry adoption studies. Agroforestry Systems 57, 173–186.

Pitt, M. M., Sumodiningrat, G., 1991. Risk, schooling and the choice of seed technology in developing countries: a meta-profit function approach. Int. Econ. Rev. 32(2), 457–473.

Ransom, J. K., Paudyal, K., Adhikari, K., 2003. Adoption of improved maize varieties in the hills of Nepal. Agric. Econ. 29, 299–305.

Robert, C. P., 2001. The Bayesian Choice: From Decision-Theoretic Foundations to Computational Implementation. Springer, New York.

Salasya, B. D. S., Mwangi, W., Verkuijl, H., Odendo, M. A., Odenya, J. O., 1998. An Assessment of Adoption of Seed and Fertilizer Packages and the Role of Credit in Smallholder Maize Production in Kakamega and Vihiga Districts. Kenya Agricultural Research Institute (KARI) and International Maize and Wheat Improvement Center (CIMMYT), Mexico, DF, 36 pp.

Shiferaw, B., Holden, S. T., 1998. Resource degradation and adoption of land conservation technologies in the Ethiopian Highlands: a case study in Andi Tid, North Shewa. Agric. Econ. 18, 233–247.

Shively, G. E. 1997. Consumption risk, farm characteristics, and soil conservation adoption among low-income farmers in the Philippines. Agric. Econ. 17, 165–177.

Smale, M., Bellon, M. R., Aguirre Gómez, J. A., 2001a. Maize diversity, variety attributes, and farmers' choices in southeastern Guanajuato, Mexico. Econ. Dev. Cultural Change 50(1), 201–225.

Smale, M., Heisey, P. W., Leathers, H. D., 1995. Maize of the ancestors and modern varieties: the microeconomics of high-yielding variety adoption in Malawi. Econ. Dev. Cultural Change 43(2), 351–368.

Smale, M., Just, R. E., Leathers, H. D., 2001b. Land allocation in HYV adoption models: an investigation of alternative explanations. Am. J. Agric. Econ. 76, 535–546.

Sunding, D., Zilberman, D., 2001. The agricultural innovation process: research and technology adoption in a changing agricultural sector. In: Gardner, B.L., Rausser, G.C. (Eds.), Handbook of Agricultural Economics, Volume 1A Agricultural Production. Elsevier, New York.

Thiam, A., Bravo-Ureta, B. E., Rivas, T., 2001. Technical efficiency in developing country agriculture: a meta-analysis. Agric. Econ. 25, 235–243.

Thirtle, C., Beyers, L., Ismael, Y., Piesse, J., 2003. Can GM-technologies help the poor? The impact of Bt Cotton in Makhathini Flats, KwaZulu-Natal. World Dev. 31(4), 717–732.

Udry, C., 1996. Gender, agricultural production, and the theory of the household. J. Political Econ. 104(5), 1010–1046.

von Braun, J., Webb, P. J. R., 1989. The impact of new crop technology on the agricultural division of labor in a West African setting. Econ. Dev. Cultural Change 37(3), 513–534.

Weir, S., Knight, J., 2000. Adoption and diffusion of agricultural innovations in Ethiopia: the role of education. CSAE Working Paper WPS2000-5, Center for the Study of African Economies, Oxford University, UK.

Wozniak, G. D., 1984. The adoption of interrelated innovations: a human capital approach. Rev. Econ. Stat. 66(1), 70–79.

Zeller, M., Diagne, A., Mataya, C., 1998. Market access by smallholder farmers in Malawi: implications for technology adoption, agricultural productivity and crop income. Agric. Econ. 19, 219–229.

Zepeda, L., Castillo, M., 1997. The role of husbands and wives in farm technology choice. Am. J. Agric. Econ. 79(2), 583–588.