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Rough Terrain for Research: Studying Early Adopters of Biotech Crops

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Measuring the economic impacts of GM crops in developing agriculture poses particular challenges. In order to ensure that information generated is relevant and usable, continued improvement in methods is needed as diffusion of these crops steadily expands. In the first decade of published studies, given the characteristics of early adoption, researchers were not often able to effectively control for various types of potential bias created by sampling, measurement, or estimation methods. Several published studies present exemplary approaches. The objective of pilot studies assembled here, all based on farmer surveys, was to attempt to apply recommended approaches within a constrained budget of $20,000-40,000 in countries and crops that had received little research attention. Case studies present findings, illustrate difficulties, and suggest means of overcoming them. Overall, we call for establishing research consortia to monitor the impacts of GM crops based on comprehensive national sampling frames in which ad hoc surveys can be embedded.

Key words*:* developing countries, economics methods, biotech crops, Bt maize, Bt cotton, HT soybeans.

The Importance of Studying Impacts of Biotech Crops in Developing Agriculture

Developing countries grew close to 50% (49.9%) of global biotech crops in 2011 and may exceed industrialized countries in total hectarage this year (International Service for the Acquisition of Agri-Biotech Applications [ISAAA], 2012). In order of total hectarage, the four largest biotech crop growers among developing countries are Brazil, Argentina, India, and China. Each is also known as a global economic leader. Brazil has been characterized as a biotech "engine of growth," where the Brazilian Agricultural Research Corporation (EMBRAPA) has recently approved its own publicly developed, virus-resistant bean (ISAAA, 2012). In contrast to these early-adopting nations, in Sub-Saharan Africa (outside of South Africa) only Burkina Faso has introduced a biotech crop (cotton). As of 2011, outside of India and China, only the Philippines and Myanmar have commercialized a biotech crop, and the Philippines is the only Asian country to have introduced a biotech food crop (maize).

Measured in terms of total hectarage, herbicide-tolerant (HT) soybean—rather than insect-resistant cotton—is the most extensively cultivated biotech crop in developing countries. Outside of the United States, many farmers who grow HT soybeans are in Latin America (Argentina and Brazil, especially), where they grow it on mechanized farms that are relatively large (well over 50 ha).

By contrast, Bt cotton farmers in India, South Africa, and China typically hand-cultivate and harvest the crop—often with family labor—and on farms of under 5 ha. In this issue, we refer to farmers who operate on this smaller scale, with limited resources, as "smallholders in developing agriculture." For additional insights, we also offer an example from a study of relatively smaller-scale, mechanized HT soybean growers in Bolivia.

Assessing the impacts of any new technology on farms is not a trivial exercise. Calculating the costs and benefits of new seed technology and related inputs has occupied the minds and journals of agricultural economists working with international research institutions since the Asian Green Revolutions in wheat and rice that began during the late 1960s (Byerlee & Traxler, 1995; Hazell, 2010; Pinstrup-Andersen & Hazell, 1985; Ruttan, 1977). Studies by Zvi Griliches (1957) on the diffusion of maize hybrids in the United States, and later by John Gerhart (1975) on maize hybrids in Kenya, were also pivotal in the early literature.

Our experience has been, however, that biotech crops have some features that exacerbate the challenges of impact measurement. Heightened political sensitivities around GM crops create additional problems related to drawing probabilistic sampling, as demonstrated by studies in Honduras (Falck-Zepeda, Sanders, Rogelio Trabanino, & Batallas-Huacon, in this issue) and Bolivia (Smale, Zambrano, Paz-Ybarnegaray, &

Fernández-Montaño, in this issue). In the case of Honduras, the list provided by the seed supplier was outdated and included only a handful of farmers. In Bolivia, not only had the government agreed to provide subsidies and support to farmers who grew non-HT soybeans, but some communities (and individuals within communities) were unwilling to participate in the survey. When farmers don't trust interviewers, responses are unreliable. Interviewer bias can permeate how questions are framed, analyzed, and interpreted.

These features are compounded by general problems of more restricted provisions of information and other market services to smallholder farmers in many developing countries. In some poorer countries, this can be compounded by lower literacy rates and fewer years of formal education. Farmers in lower-income countries have heard less—either pro or con—about biotech crops. A number of studies of consumer preferences in Asia, for example, have demonstrated that the sensitivity of attitudes and preferences are information- and time-dependent (Smale et al., 2009). However, willingness-to-pay estimates seem to be most influenced by methods (Dannenberg, 2009; Lusk, Jamal, Kurlander, Roucan, & Tualman, 2005). Few studies have used a stated-preference framework to analyze biotech crop (as compared to product) choices (Birol, Smale, & Yorobe, in this issue), and these have not yet examined changes over time.

Since the Green Revolution literature, the adoption of agricultural innovations has been conceptualized as a process guided by farmers learning about uncertainty and risk (Feder & Slade, 1984; Foster & Rosenzweig, 1995; Griliches, 1957). Variability of net returns generally rises with mean returns. Some posit that biotech crops are riskier for farmers than their conventional counterparts, although this is a testable hypothesis. Even if they are not, in fact, riskier, early adopters know less about their performance and characteristics than they do about the now more familiar, conventionally improved seed.

In the case studies presented here, not only the farmers studied, but the researchers who studied them were in the process of "discovering" biotech crops—how to grow them and how to study them. During the first decade of their introduction, "discovery" by researchers entailed some fundamental limitations.

A goal of several of the studies included in this special issue was to propose good practices for assessing the social and economic impacts of biotech crops on smallholders in developing agriculture—with a constrained budget and short funding period similar to those that are typically available to applied economists housed in national universities or research institutes. Field-research budgets for the Bolivia, Colombia, Honduras, and Philippines cases were $20,000 to $40,000. This exploratory work was funded by the International Development Research Centre, Canada as part of a 2-year project. The project aimed to support biosafety policy-making through developing and testing a "good practices" methodology for assessing the social and economic impact of transgenic crops on smallholder farmers. In the process of implementation, researchers also sought to generate new information.

Reviewing past studies made it easy to pinpoint shortcomings, and references to recent economics literature provided examples of cutting-edge approaches. Applying these in the field was far more difficult. In the studies collected here, each of the research teams attempted to apply a new twist to a known applied method, and each encountered major challenges. These are presented along with a description of the methods and findings.

In the next section, we present a numerical summary of the articles in the literature. We then summarize the major limitations of the early literature, citing some articles which we consider to be exemplary. In the fourth section, we provide a preview of the studies summarized in this special issue collection, highlighting some of the methodological challenges faced by study teams.

Before proceeding, it is important to underscore that our purpose in critiquing "how we do our work" is not to invalidate the research that has been conducted. Knowing the boundaries of a scientific protocol improves our capacity to interpret and understand the results. Some types of errors may not significantly alter results. So far, all meta-analyses of findings measuring the performance of Bt cotton (Finger et al., 2011; Qaim, 2009; Raney, 2006; Smale et al., 2009; Sexton & Zilberman, 2011; Tripp, 2009) have concluded that on average, Bt cotton has raised yields, reduced losses from pests, reduced insecticide costs, and raised gross margins of cotton producers where adopted by developing countries. This does not imply, of course, that all farmers who grow Bt cotton benefit from it. There is tremendous variation in the magnitude of costs and benefits within and among countries. Evidence for smallholders (under 50 ha) in developing countries is not yet as extensive for HT soybeans and Bt maize. Furthermore, the fact that there is evidence of profitability does not imply that the technology performs as well as expected. Both Raney (2006) and Tripp (2009) argue the importance of institutional capacity to ensure that farm-

Table 1. Number of articles examining the economic impact of biotech crops in developing agriculture as of August 30, 2011.

	Pre-2005	2006	2007	2008	2009	2010	2011	Total
Farmers	51	18	10	21	17	5	5	127
Consumers	14	13	4	9	4	2	1	47
Industry	17	6	6	13	5	1	0	48
Trade	17	6	4	2	2	2	1	34
Review findings	17	5	0	3	5	3	0	33
Review methods	7	3	2	2	2	1	0	17
Cost of regulation	1	2	1	0	1	2	1	8
Others	0	1	0	0	1	2	3	7
Total	124	54	27	50	37	18	11	321

Source: Indira Yerramarreddy and Patricia Zambrano, International Food Policy Research Institute.
Note: "Other" includes biosafety and biodiversity.

ers—and especially poorer farmers in poorer countries—benefit from the potential of the technology.

A Numerical Summary of the Literature

Since the introduction of biotech crops to commercial markets in 1996, more than 125 articles that document their economic impacts on smallholder farmers in developing agriculture have been published in peer-reviewed journals. As of 2008, the most well-represented crop was insect-resistant (Bt) cotton, and studies conducted in South Africa, India, and China were the most frequently published (Smale et al., 2009). This continues to be true in 2012.

We conducted a systematic review of all literature published in English, French, and Spanish, combining databases available online, web-bibliographies related to biotechnology, references cited in published articles, and direct communication with economists working on the research questions. Only peer-reviewed articles with a stated economics method that were conducted in developing agricultural countries were selected. After examining their content, a total of 321 articles met these criteria as of August 30, 2011. They are grouped by major economics research question, which corresponds roughly to the sectors of the economy (farmer, consumer, industry, trade, etc.), in Table 1.

Of the papers using primary data analysis, about half examine impacts on farmers (127). Studies of consumer acceptance and industry impacts are next in numbers (47 and 48, respectively). Analyses of international trade follow (33). More than 1 in 10 articles are reviews, which seems to be a high proportion of secondary to primary research. There are several articles on the costs of regulation, biodiversity, and biosafety. The total numbers appear to have declined in recent years.

For the purposes of comparison with our numbers, Finger et al. (2011) searched for all examples of measurements of yield gains, gross margins, and economic performance, and did not limit their search to developing agriculture. They found 203 publications based on field trials or farm surveys. As in our search, the most frequently studied outside of the United States were farmers in India, South Africa, and China.

Promises and Pitfalls of Early Analyses of Farm Impacts

In this section, we reiterate the major methodological limitations that characterized early literature and cite some examples of research that was outstanding in this regard. We consider only the articles that evaluated impacts on farms.

Data Design

Perhaps the most important fact that differentiates research in developing agricultural economies from those of industrialized agricultural countries is the absence of nationally representative, statistical frames for sampling agricultural production units with known probability of selection. By contrast, this frame exists for US agriculture, generating a steady stream of data for analysis of trends in biotech crops from initial adoption.[1] At this point in time, researchers studying biotech crops in developing agriculture generally have three less-attractive options. Not only are they less attractive, but the value of the information generated is less for policy purposes.

1. *See http://www.ers.usda.gov/Briefing/ARMS/.*

The first is to utilize trial data generated from research stations or on-farm demonstrations. These are known to differ from farmer conditions because the data are collected from controlled experiments or the farms on which demonstrations are placed are not broadly representative or are of unknown representation. Such data are useful for exploratory, ex ante analyses based on potential, but not for gauging actual impacts on differentiated farms. An example is the article by Qaim and Zilberman (2003), which was exemplary in technique, but generated substantial controversy in a developing economy with a civil society that is considered to be well-developed (India).

A second option is to utilize company data, where company agents in vertically-integrated industries (such as the cotton industry) retain farm records. Given the polarization in the debate over biotech crops, the viability of such analyses is often questioned, despite the fact that these can consist of large samples, can generate time-series data, and provide useful information. Many of the studies in the literature are based on such analyses.

A third option has been to conduct ad hoc surveys (not grounded in a nationally representative, statistical sampling frame) with the constrained budgets common to universities or research institutes. Constructing a sampling frame for farm surveys of biotech crops can be particularly costly and difficult due to lack of information and political sensitivities.

Consequences of the preponderance of ad hoc, budget-constrained field studies among early adopters include relatively small sample sizes, selection bias, and measurement bias. Many of the first-generation studies are based on very small samples, reflecting the fact that they were implemented in the early phases of adoption. They also exhibit a placement bias, since initially, promotional programs were often initiated with a unique group of farmers—either because they were more efficient, or they were targeted for other reasons. This type of bias is often recognized by the authors themselves. In other cases, early farmers "self-select" into the adopting group precisely because they have more information; greater access to new seeds and techniques; or have some idiosyncratic, unobserved characteristics that are difficult to identify in survey research. Measurement bias has been common because of the need to survey cheaply and rapidly. Farmer recall was the primary means of obtaining estimates of impacts on labor and pesticide use, although the practices used by farmers to combat pest pressures are complex, and monitoring practices through multiple visits would be recommended. Accurate measurement of labor input in agriculture is notoriously difficult. As is true in any survey research, sampling error of smaller samples is traded for measurement error in larger surveys.

Smale, Niane, and Zambrano (2010) analyzed the methods used to measure impacts on farmers through 2007, spanning the first decade since the introduction of biotech crops in developing agriculture. The most common approaches employed were partial budgets, followed by farm-production and input-use models. A small subset of articles used variety choice models based on revealed or stated preferences, value chain analysis, or mathematical programming. Only the partial budgets and econometric models are discussed here. These are essential tools of economic impact assessment, underpinned by the appropriate sample design.

Partial Budgeting

Partial budgeting is the simplest approach used by agricultural economist to test hypotheses concerning the effects of Bt crops on yield losses from pests, insecticide use costs, labor use costs, and profits, or of HT crops on herbicide use, labor use, and profits.

Conceptual limitations of partial budgets are well-known. For example, in most early studies, margins presented are gross, rather than net, and do not consider land or labor costs. Second, a whole-farm perspective would provide a better indication of the impacts on overall resource allocation. In addition, the partial budget approach must be modified to better represent the conditions of farmers who are not fully oriented toward commercial production, whose families constitute the primary source of labor, and who purchase and sell on poorly functioning markets. The theoretical framework of the agricultural household model is arguably more appropriate than profit maximization in many contexts in which studies have been implemented. In a partial budgeting context, this would suggest sensitivity analysis with price bands that represent transaction costs. Most early studies ignored risk in partial budget analysis. The treatment of risk, through application of stochastic budgeting, has therefore represented a crucial advance.

Recall has often been used to measure insecticide use, although farmers are often unfamiliar with the names of the insecticides they apply, or mix them, or do not remember amounts applied. Some researchers have designed more-effective protocols, introducing a strong agronomic component to the research. Hofs, Fok, and Vaissayre (2006) employed daily monitoring of practices, including all types of pesticides used by farmers, combined with isogenic lines. Pemsl, Waibel, and Orphal (2004) and Pemsl, Waibel, and Gutierrez (2005) took leaf samples to test toxin expression and applied stochastic analysis of farm budgets.

Econometric Models of Production and Input Use

Most econometric analyses of the impacts of Bt crops have served to test the same hypotheses mentioned above with more advanced statistics in a multivariate framework. Other methods test the impact of adoption on production efficiency. The quality of econometric analysis, in turn, is based in part on the quality of the data. In some cases, the same small samples have been used for successive econometric analyses, entailing some test bias. That is, the number of independent authors and datasets is narrower than the number of articles published.

Early studies typically estimated yield response or production functions, or insecticide use equations, with a dummy variable included as an explanatory variable to test the effect of adoption. Major progress was made for studies of Bt crops with the application of damage-abatement models (originally proposed by Lichtenberg & Zilberman, 1986). These explicitly recognize that Bt, like insecticides, serve to reduce yield loss in the presence of pest pressures rather than raise yields—as does fertilizer.

Other challenges remain. By far the most important consideration is the bias associated with self-selection of more-efficient farmers—or those with greater endowments and access to information and resources—into adoption. Another is the endogeneity of the decision to grow a biotech crop. Unobserved factors can affect this choice and/or the decision to use insecticides or herbicides, as well as farm yields or other indicators of outcome. Presence of endogeneity was rarely tested in early studies, leading to potential bias in estimated impacts. Until recently, treatment of selection bias and endogeneity was uncommon in published studies.

Several articles are exemplary in their treatment of selection bias and endogeneity. Qaim and de Janvry (2005) estimated an insecticide-use function, an instrumental variable model with insecticide use and a production function, and a production model with damage abatement. By evaluating conditions on Bt and non-Bt plots operated by the same farmer, selection and placement bias are effectively controlled. The authors also incorporated a physiological model of the Bt cotton-test system calibrated with entomological data in order to draw inferences about the size of the refuge areas needed to ensure that farm benefits are sustained.

In one of their early—but most comprehensive—analyses in China, Huang, Hu, Fan, Pray, and Rozelle (2002) estimated a production function using the damage-abatement framework. Applying an instrumental variables model, the authors showed that farmers chose the amount of insecticies applied in response to pests. They also attempted to correct for the endogeneity of insecticide application in the decision of farmers to grow Bt cotton. Their findings suggested that growing Bt cotton had a favorable effect on yield as well as on reducing pest damage, reflecting the germplasm into which the trait was inserted.

Similarly, one of the most comprehensive analyses in South Africa was conducted by Shankar and Thirtle (2005), based on the original small sample of Bt cotton growers of Makhathini Flats. In the context of a production function estimated with the damage-abatement model, the authors explicitly tested the endogeneity of insecticide use, as well as the selection bias among adopters, applying a combination of statistical approaches with a thorough discussion of methods. In comparison with the findings of Huang et al. (2002), they concluded that farmers applied pesticides in a predetermined, prophylactic way, rather than in response to pest pressures. They also concluded that adoption was supply- rather than demand-driven, finding no evidence of self-selection bias. The uniqueness of Makhathini Flats, and thus the difficulty in generalizing the case, was recognized here and in earlier work by the same authors.

Approaches based on panel estimation do not appear to have been published until 2007. Crost, Shankar, Bennett, and Morse (2007) used a fixed-effects model with panel data to control for both endogeneity and self-selection bias. Although they found evidence of selection bias toward more efficient farmers in Bt cotton adoption, the impacts on yield were statistically significant despite selection bias. Their paper is thus significant in at least three ways: use of panel estimation, overt recognition of selection bias, and demonstration that selection bias will not necessarily invalidate findings. Whether or not selection bias matters depends on the relative magnitudes of the bias and the change in the impact-outcome variable.

Since then, a number of studies have sought to control for selection bias using various methods, including Heckman models, instrumental variables, panel fixed-effects models, and propensity score matching. To our knowledge, randomized controlled trials to examine the economic impacts of biotech crops in farmers in developing agriculture have not yet been published. Though perhaps the dominant methodology used to examine impacts in other fields, the political sensitivity of biotech crops may again render these approaches more inappropriate.

Several articles published since 2007 bear special mention with respect to the methods applied. An article by Mancini, Termorshuizen, Jiggins, and van Bruggen (2008), which focused on integrated pest management and farmer field schools in cotton production in Andhra Pradesh, nonetheless included several innovations of potential use in other studies. First, they applied a double-difference approach, comparing impact outcomes for control and test groups. Second, they employed canonical correlation analysis among villages to control for placement bias. One of the general conclusions of the authors is that mere substitution of synthetic pesticides with biocontrol agents of Bt varieties is “unlikely to become a definitive solution…unless these new technologies are paired with educational programs for farmers, spray operators, hired workers, and family members who also work the crop” (Mancini et al., 2008, p. 23).

Ali and Abdulai (2010) applied propensity score matching to examine the effects of Bt cotton adoption in the Punjab of Pakistan. The authors found that adoption positively influenced yields and income, and reduced use of pesticides and rural poverty. Kouser and Qaim (2011) applied panel data estimations with fixed effects to test the effects of Bt cotton use on pesticide poisoning, employing a Poisson regression model to explain incidence of poisoning. These papers are exemplary not only in terms of their models but also in terms of the outcome variables measured—poverty and health.

Finally, as mentioned above, risk has been infrequently incorporated into partial budget analysis. Crost and Shankar (2008) investigate production risk using a Just-Pope mean-variance production model and a second model with different assumptions about error structure, based on data from both India and South Africa. They find that Bt cotton reduces yield risk in India, but their results for South Africa are inconclusive.

Some of the models used by the papers published before 2007 guide the designs that research teams sought to implement in the case studies presented in this *AgBioForum* special issue; all the case studies were implemented in 2006-2007. Case studies in this issue are previewed next.

Case Studies in this Collection

The purposes of the research presented in this collection were to a) identify and pilot test research methods, b) document challenges and constraints of their use with limited budgets and time frames, and c) propose good practices. Case studies for pilot testing were selected based on the fact that either the country or the crop had not yet been heavily studied. Little was known about the research context prior to initiating the studies. With the exception of South Africa, all are early-adopting farmers in later-adopting countries. In South Africa, the technology studied (HT maize) has been newly introduced. In none of the cases was application of panel data methods (Crost et al., 2007; Crost & Shankar, 2008; Kouser & Qaim, 2011) feasible given the length of the funding period and budget constraints.

The articles in this collection document the challenges experienced by researchers seeking to measure, as accurately as possible, the economic impacts of biotech crop in these contexts. In general, studies were implemented with constrained budgets and short time frames. In some cases, the institutional and political environment was an impediment. Concrete examples illuminate the practical realities of conducting research on biotech crops. Each case contains a brief summary of challenges and how they were addressed. Our experiences lead us to recommend a consortium approach to undertaking field research on the impacts of biotech crops, including a range of stakeholders, a trans-disciplinary set of research protocols, and funding that supports the development of a statistically valid, national sampling frame in which ad hoc surveys and monitoring exercises can be nested, when needed.

Bolivia: Herbicide-tolerant Soybeans

The Bolivia study (Smale et al., in this issue) highlights some the challenges of conducting research in an environment with heightened political sensitivity to GMOs, as well as an active government program to furnish subsidized inputs, credit, and information to non-HT growers. The Bolivian National Constitution prohibits the commercialization of genetically modified organisms, but the decree permitting the unique event of glyphosate resistance was enacted earlier. HT soybean is the only transgenic crop grown by farmers in Bolivia, and it was introduced initially by farmers. Another challenge was exceptional weather related to El Niño and La Niña during the survey period. In addition, the settlement pattern often involves residence of the household away from the fields during much of the year.

The primary region of soybean production is the Department of Santa Cruz de la Sierra. Social aspects of soybean production affect adoption patterns, the supply of seed, and seed information. Most growers are not indigenous to Santa Cruz but migrated into the region both spontaneously and as a consequence of deliberate policy to colonize the area, each with its own settlement pattern. Mennonite farmers who migrated from other countries, including Canada and Mexico, are a primary source of HT seed and related information. The association that subsidized non-HT growers is the major source for conventional seed.

Political sensitivities and weather influenced data collection in the following ways. First, only certain areas, communities, and farmers were willing to be interviewed. Second, no list of HT growers was available, even to the national producers' association. Third, the team sought to sample only from the sub-population of smallholders in a region where most growers are large. Developing the sampling frame required three visits to the field, which was logistically difficult and absorbed much of a modest budget. Fourth, extreme weather conditions decimated yields and made it impossible to reach the area during the initial year due to flooding. Fifth, the final stage of sampling and interviews had to be conducted during the harvest, in a brief time period when farmers were reluctant to participate. The final sample consisted of 146 growers.

The hypotheses tested in the study were generated by the social aspects of HT soybean introduction and by previous research on this topic in Argentina and the United States (Fernandez-Cornejo, Hendricks, & Mishra, 2005; Qaim & Traxler, 2005). The study team hypothesized that a) social networks shape the diffusion of HT soybeans among growers, b) the use of HT soybeans reduces application of toxic chemicals, and c) the use of HT soybeans frees management labor for other income-generating activities.

Using an instrumented, control-function approach, the authors find that HT soybean adoption has a large, positive association with household off-farm income and is positively related to off-farm work of the second-major contributor to soybean production (wife or children of household head) but not that of the first (household head). Descriptive statistical tests support the hypotheses that adoption of HT soybeans is associated with use of less-toxic pesticides and that Mennonite farmers are a primary source of HT seed and related information.

Data and findings must be interpreted in the context of the caveats cited above. For example, we cannot be assured of the representativeness of the study, and it should be interpreted as a pilot, to be followed by a more comprehensive analysis. The team was not able to develop a sample design with a treatment (adopting) and control (non-adopting) group in order to estimate a treatment model, given the lack of underlying information about the grower population. Since only a few farmers grew both types of seed, the approach of Qaim and de Janvry (2005), which compares plots for the same farmers, could not be employed. There is also considerable heterogeneity among growers that cannot be well-captured in the small sample size; it also influences the reliability of adoption estimates. For example, being Mennonite perfectly predicted adoption. In the future, a stratified sampling procedure that takes into account the nature of colonization and social organization, as well as farm sizes, might be appropriate if complete producer lists and estimate variance in key parameters would be available.

Colombia: GM Cotton

Gender has been understudied in the published literature about crop biotechnology in developing countries, and qualitative approaches are underutilized as means of interpreting, supporting or refuting the findings of quantitative analyses. Zambrano, Smale, Maldonado, and Mendoza (in this issue) sought to address these two lacunae in a pilot study about differences in perceptions of men and women with Bt cotton in Colombia. The pilot study examines hypotheses that emerged during an earlier, small-scale, statistical survey (Zambrano, Fonseca, Cardona, & Magalhaes, 2009). Zambrano et al. (2009) had noticed that women were more involved in cotton production than was expected, even given the experiences of the national producers' association, which is led by a woman and co-author.

The research team developed a participatory, qualitative approach that included interviews and focus groups with managers of cotton producer associations, technical assistants, and female and male farmers. Instruments were designed to explore gender perceptions, use, cost, and benefits of biotech cotton that are not always easy to spot with typical, quantitative household surveys. Instead of relying on the perception of the researchers or multiple-choice survey questions, qualitative methods can allow the subjects of research to become active participants. The intervention of the researcher is limited to the design of tools that facilitate the engagement of farmers and others in discussion. Professional facilitation, or training of the research in facilitation, is preferred. Here, findings are represented as drawings or diagrams prepared by farmers, and counts are summarized in tables. Other methods, which were not used here, include textual analysis of taped interviews, photos, and videos made by farmers.

The study confirms that women participate in several crop operations, including some that were previously invisible. One of the most useful aspects of the research was the interactive development of a detailed cost-of-production template, which improved on the template previously used by the national producers' association, and also exposed some changes in cotton production processes that the introduction of Bt varieties created.

Some women successfully manage or share production responsibilities with their spouses. Men and women also appear to perceive the costs and benefits of Bt cotton differently. Female farmers who managed their own plots stated that they preferred insect-resistant varieties over conventional varieties primarily because these reduce the number of laborers they need to hire to spray pesticides, a task performed solely by men. Both male and female farmers identified the lack of adequate and timely information about Bt cotton as a major disadvantage, but the problem is accentuated by female farmers. Although findings cannot be generalized, they can be tested in future statistical studies. Methods of this type provide valuable insights that cannot be obtained with formal survey instruments.

A noteworthy limitation of the methods employed, which were time-intensive, was that the actual participation of women was lower than expected, despite efforts of the team and the provision of meals. The team concluded that the demands on women's time are greater compared to their male counterparts, because domestic chores and responsibilities are unequally shouldered. Provision of appropriate incentives could overcome this challenge.

The obvious shortcoming of the methods used here is that they are not generalizable because of small and voluntary (self-selection) samples. The generalization of the findings of this method requires the design of a randomized sample where all respondents have a known probability of selection. Hypotheses raised by this pilot study, such as the notion that female farmers prefer to grow biotech cotton because it saves them labor and management time, could be tested in a larger, stratified random sample of growers in which the preferences choices, expenditures, and income of female managers and wives of male managers are each compared statistically to those of male managers. We recommend tools such as these as one component of mixed qualitative and quantitative methods.

Honduras: Bt Maize

Insect-resistant and herbicide-tolerant (Bt/RR) maize was approved in Honduras in 2006. Honduras is the first and only country in Central America to render biosafety regulatory approval and commercialize a genetically modified crop. Commercial plantings have increased slowly but consistently, reaching approximately 30,000 hectares by 2011. Currently, Bt/RR maize planting is permitted in four states ("Departamentos") in the country including La Paz, Comayagua, Yoro, and Olancho. Yoro and Olancho produce approximately 90% of the total maize in the country. This planting restriction was established in the biosafety permit authorized by the national biosafety committee of Honduras, to protect against the potential out-crossing of the Bt/RR maize pollen with native, open-pollinated maize.

There were approximately 3,000 hectares planted with GM maize in Honduras in 2007, when the research presented by Falck-Zepeda et al. (in this issue) was conducted. To examine the potential impact of Bt/RR maize hybrids in Honduras, Falck-Zepeda et al. designed a research package consisting of two major components. The first component was led by agronomists. In the first component, they conducted 1) an agronomic evaluation of primary and non-target insect pests in a randomly-selected experimental field comparing isoline hybrids and a widely grown, improved open-pollinated variety; 2) a study of Bt/RR maize effectiveness *in situ* on larger plots of medium- and large-scale producers, and 3), a Farmer Field School based on experimental plots managed by smallholders in different areas of the country (including various exercises and a video). The first activity generates accurate data on comparative yields in the presence of pests. The second enables researchers to examine performance on slightly less controlled conditions like those of commercial growers. The Farmer Field School activity gave researchers a glimpse of smallholder perceptions of the new technology. The second component of the overall package was an exploratory survey of initial adopters, conducted by agricultural economists in two Departamentos of the country. The research package, which combines various methodological approaches and was relatively inexpensive to implement, provided a fairly comprehensive snapshot of the potential for GM maize in Honduras at that time.

In the context of the methodological points raised in this introductory chapter, perhaps the foremost limitation of this research related to the second component. The team attempted to obtain a list of producers with the relevant Ministries and the technology developer but was unsuccessful in obtaining a list of Bt/RR maize users that was up-to-date or complete. They then opted for a combination of snowball and referral sampling. The two enumerators hired to conduct the field work contacted seed retailers and marketers in the Departamentos were the survey was conducted and built a list of producers that used Bt/RR maize in the three study sites. The final sample includes only 67 Bt/RR growers and 47 conventional maize growers. The size was constrained by the time frame and survey budget.

The agronomic evaluation confirms that Bt/RR has a yield advantage over the conventional hybrid under controlled and semi-controlled conditions in large plot conditions like those that pertain to commercial farmers with good management practices. This preliminary finding suggests only that the potential for generating benefits for the farm sector and consumers in Honduras, under superior farm conditions, is sizeable. The bulk of the domestic maize crop is produced by medium- and large-scale farmers who have greater access to new technologies such as improved varieties, and most importantly, financing by the banking sector. However, the majority of maize producers in Honduras have small land holdings and produce mostly for subsistence. Most of these farmers have little access to technology, knowledge, and credit. Still, to the extent that subsistence-oriented growers are also net consumers of maize, increasing the supply of maize could benefit them through lower consumer prices. Future analyses might investigate the net social distribution of benefits.

Farmer Field School results also demonstrated yield advantages of Bt/RR maize. In terms of perceptions, nearly two-thirds of smallholder farmers (61%) indicated that they would adopt the Bt/RR technology, slightly under one-fifth (18%) indicated that they would adopt if they were not financially constrained, and about one-fifth of farmers (21%) indicated that they would not adopt the technology. Those who stated that they would not adopt cited seed price and access to seed (distance) as the primary reasons.

To cope with the data problems in the exploratory survey, team economists used robust regression, instrumental variables regression, and stochastic dominance analysis with SIMETAR to analyze yield response and net returns. Findings indicate that adopters benefit from yield advantages compared to non-adopters and obtain higher returns over variable costs. However, when the authors correct for selection bias and adoption endogeneity using instrumental variables regression, results change substantially. Early adopters in Honduras tend to be those who have larger farmers and are better managers because they have with more access to credit, irrigation, technical assistance, and/or other attributes.

The experience analyzing sparse survey data in Honduras illustrates how disregarding endogeneity can lead to inaccurate impact measurement, but also what happens when researchers attempt to address multiple limitations. The authors recommend triangulating methods and approaches, and particularly those that include other disciplines. However, we find the combination of methods proposed, and the econometric estimation methodology, to be of great potential use to applied researchers working on this topic.

Philippines: Bt Maize

The only country in Asia that has approved a biotech food or feed crop is the Philippines, where Bt maize was initially commercialized in 2003. Bt maize, which is yellow in color, is produced as a feed crop in that nation. Two studies on Bt maize in the Philippines are presented here, based on data collected from 466 farms in Isabela and Cotabato Provinces. In one, Birol et al. (in this issue) apply the choice experiment method and a latent class model (LCM) to differentiate among maize producers and estimate their willingness to pay for Bt seed and other important attributes. Two segments are identified with different socio-economic characteristics, markedly different willingness to pay, and different preferences with respect to information and method of seed acquisition. The bi-modality of preferences confirms the importance of marketing and extension strategies that are tailored to the diversity of farm populations and agro-ecologies of the maize sector in the Philippines. They also conclude that the supply of credit for seed acquisition is likely to constitute an important policy instrument for diffusing all improved, yellow maize seed, including both biotech and non-biotech hybrids. The authors consider the choice experiment method as the most appropriate model to investigate the preferences of new seed adopters, but caution applied researchers regarding framing and preparation of the choice experiment.

Published economics research about the impacts of Bt maize adoption among smallholder farmers in the Philippines has gradually accumulated, focusing on partial budgets, yield, and damage abatement. In initial estimates of the effects of Bt maize adoption on income, selection and endogeneity bias were not explicitly considered. This study adds new information concerning the economic impacts of Bt maize on net farm income, off-farm income, and total household income among smallholder farmers in the Philippines. The authors employ a quasi-experimental approach with two types of instrumental variable estimation to account for selection and endogeneity issues. The first is the usual two-stage regression, in which the predicted probabilities of Bt maize adoption from a first-stage probit regression are included in a second-stage regression explaining income rather than the observed value of the binary variable. Instrumental variables are utilized to identify the effect of adoption on income, subject to diagnostic tests. The second method used is a three-step procedure with a zero stage, beginning with a probit regression to predict Bt adoption, followed by a second probit to regress predicted adoption. The predicted values from the second regression are used to estimate impacts of Bt adoption on income variables. Bootstrapping is used to adjust the standard errors. As instruments, authors tested the validity of seed price and distance to seed source. Tests indicated that adoption is endogenous in net farm income and off-farm income, but not in total household income.

Findings demonstrate the substantial income benefit (net farm income) that accrues to smallholder maize farmers from adopting Bt maize. In fact, estimates suggest that accounting for selection and endogeneity biases augments the marginal effect of adoption at the mean. The magnitudes of the two instrumental-variables estimates are similar, although the second approach generates estimates that lie between ordinary least squares and the first instrumental-variables estimators. Kernel density functions for predicted income values demonstrate that the use of Bt maize reduces the probability of falling below the poverty threshold as compared to those using the conventional hybrid.

South Africa: HT Maize

The South African smallholder Bt cotton case was one of the most widely cited and intensively studied among the early-adopter experiences, and it is of particular interest to other cotton-producing countries in Sub-Saharan Africa. An investigator in much of this work on cotton, in this collection, Gouse presents an honest and insightful story of the experience of GM maize introduction among smallholders in South Africa. The research he has conducted spans eight years.

South Africa's experience has, to-date and internationally, been the only example where a subsistence crop is produced by smallholder, resource-poor farmers using GM seed. Their experience is thus of great interest, especially to African decision makers, international food and agricultural organizations, and the technology innovators. As part of this collection, the main objective of Gouse's rendition is to highlight methodological and practical research challenges faced in this project in order to inform future socio-economic impact assessments and to contextualize research findings.

First, the piecemeal process of introducing Bt maize, followed by HT maize, is documented, illustrating initial constraints both in terms of demand and seed supply. Supply constraints, like those explained earlier for the case of Bt cotton, are institutional in nature. Second, Gouse details research challenges from small sample sizes, as well as measuring output and plot sizes to complex counterfactuals associated with multiple traits and a changing set of adopters. He then presents a chronology of seasons and how weather and institutional aspects confound estimates of partial productivity (yield). This portrayal is very informative concerning the challenges faced by researchers in assessing economic impacts of biotech crops among poor, smallholder farmers in rain-fed agriculture.

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