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A Case of Resistance: Herbicide-tolerant Soybeans in Bolivia

Melinda Smale
Michigan State University

Patricia Zambrano
International Food Policy Research Institute (IFPRI)

Rodrigo Paz-Ybarnegaray
Fundación Valles, Cochabamba

Willy Fernández-Montaño
Independent Consultant

The Bolivian National Constitution of 2009 prohibits the commercialization of genetically modified organisms, but the decree permitting the unique event of glyphosate resistance was enacted earlier. Herbicide-tolerant (HT) soybean is the only transgenic crop grown by farmers in Bolivia, introduced initially by farmers. This pilot study of smallholders was conducted in the midst of political sensitivities and exceptional weather. Results support the hypotheses that adoption of HT soybeans is associated with use of less toxic herbicides and that Mennonite farmers are a primary source of HT seed and related information. The association that subsidized non-HT growers is the major source for conventional seed. Using a control function approach to address endogeneity and selection bias with censored outcome variables, we find that HT soybean adoption has a large, positive impact on 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).

Key words: Bolivia, HT soybeans, off-farm income, social networks, toxicity.

Introduction

The adoption of herbicide-tolerant (HT) soybeans[1] in Bolivia deepens our understanding of the dimensions of biotech crops in extremely poor countries. In 2009, Article 255 (#8) of the new Bolivian National Constitution (Gaceta Oficial del Estado Plurinacional de Bolivia, 2009) prohibited the importation, production, and commercialization of genetically modified organisms (GMOs) Article 408 added that the production, importation, and commercialization of transgenics shall be regulated by law. In fact, a law enacted in 2005 (Gaceta Oficial, 2005) authorized the commercialization of one event of glyphosate resistance.

HT soybean is the only transgenic crop grown by farmers in Bolivia; the crop was introduced initially by farmers who brought the seed from Argentina and Brazil. The anti-GMO perspective of the national government and public groups has also been reinforced by direct incentives to grow conventional soybeans. As part of the People's Trade Agreement (TCP) and the Bolivarian Alliance for the People of Our America (ALBA), the government of Venezuela furnished credit to small-scale farmers who produce and export non-HT soybeans (Bolpress, 2007).

At the time of this research, very little was publicly known—even by the national oilseeds producers organization (Asociación de Productores de Oleaginosas y Trigo [ANAPO])—concerning the use of HT soybeans. The Bolivian constitution of 2009 requires periodic revision of the norms governing the use of this technology, taking social and economic considerations into account. In response to this requirement, the results of a pilot field study conducted in 2007-2008 are presented here.[2]

Soybean is a cash crop that is not native to Bolivia, but it is important to the Bolivian national economy as an industrial export crop. The mechanized organization of soybean production means that most growers are not smallholders by the global standards of hand-hoe agriculture but are of very small scale from the perspective of the soybean sector in the United States or any other Latin American producer of the crop. The region of Santa Cruz, where soybean production is concentrated, is one of the more economically developed, commer-

1. *HT soybeans were marketed by Monsanto in the United States for the first time in 1996 under the brand name Roundup Ready (RR) soybeans. RR soybeans contain a gene from the soil bacterium Agrobacterium tumefaciens, which makes the soybean plant tolerant to the wide-spectrum herbicide glyphosate.*

2. *The study was led by an independent consultant with support from ANAPO and the International Food Policy Research Institute and funded by the International Development Research Centre, Canada. The detailed final report, written in Spanish, is available from the authors. This article excerpts the final report and adds primary and secondary analysis.*

cialized areas in the country. Santa Cruz is located in a region of the Amazon that was colonized relatively recently, both deliberately and spontaneously.

Despite the fact that HT soybeans are the predominant GM crop worldwide, and numerous analyses of transgenic crops in international trade include the crop because of its economic importance, there are few peer-reviewed studies that analyze its social and economic impact on farmers in developing countries. Most in-depth studies have been conducted in the United States and Argentina. In Argentina, Qaim and Traxler (2005) and Penna and Lema (2003) found little impact of HT soybeans on yields, but Qaim and Traxler (2005) concluded that herbicide costs and toxicity were lower and returns per hectare more favorable with adoption. Evidence that net returns to HT and non-HT soybean production were not significantly different in the United States led to the hypothesis that farmers adopted because it facilitated more flexible use of their time. Fernandez-Cornejo, Hendricks, and Mishra (2005) tested this hypothesis formally, concluding that adoption of HT soybeans increased off-farm and total household income, but not farm income. Applying a treatment model across GM crops in the United States, Gardner, Nehring, and Nelson (2009) found labor savings only in the case of HT soybeans. A recent expert review also noted that farmers who use HT soybeans in the United States spend less time in their fields (National Research Council, 2010).

Evidence concerning the economic impacts of HT soybeans in the United States, as well as the fact that HT soybeans were introduced to Bolivia by farmers themselves, has generated three working hypotheses: 1) use of HT soybeans reduces application of toxic chemicals, 2) growing HT soybeans frees management labor for other income-generating activities, and 3) social networks shape the diffusion of HT soybeans among growers.

We begin by outlining the social and economic context of HT soybeans in Bolivia. Next, we discuss methodology. Selected characteristics of HT and non-HT growers are presented in the fourth section, followed by findings. We present our conclusions in the sixth section and propose some methodological recommendations for further research.

The Social and Economic Context of HT Soybeans in Bolivia

Soybeans are by far the most widely cultivated industrial crop in Bolivia. After an impressive increase in soy

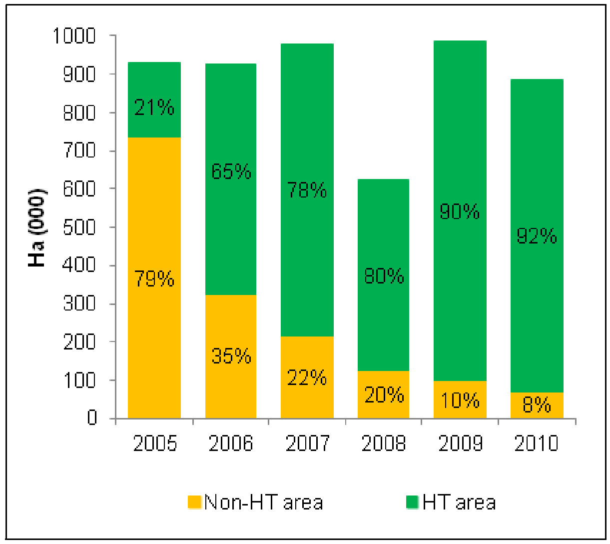

Figure 1. Percentage distribution of HT and non-HT soybean areas planted in Bolivia, 2005-2010.

Source: Based on data published in Zeballos-Hurtado (2011) from ANAPO.

production in Bolivia from 1991 to 2005, production seems to have stabilized at around 1.6 million metric tons. An exception to this pattern is the 2007-08 season, when production reached only 1.2 million, due in part to poor weather conditions (El Niño, followed by La Niña). Our survey research was conducted in 2008. According to the National Institute of Statistics of Bolivia (Instituto Nacional de Estadística de Bolivia [INE], 2011), in 2007, the value of soybean exports was roughly US$400 million, representing 8.5% of the total value of exports from the country; soybeans placed third in total export value, after natural gas and minerals. By 2010, the value of soybeans exports had grown to US$554 million (INE, 2011).

The percentage of area planted to transgenic soybean also rose steadily since its informal introduction by farmers and official approval in 2005 (see Figure 1). According to ANAPO, the estimated area share of HT soybeans was 21% in 2005, 78% in 2007, and 92% in 2010 (Zeballos-Hurtado, 2011).

Smallholders have a major presence in Bolivian soybean production. Since soybean production is fully mechanized and extensive, a smallholder is defined in Bolivia as a farmer who plants fewer than 50 hectares of the crop. In the year of study, ANAPO estimated that there were 14 million soybean producers in the country, of which 77% operated on a scale under 50 ha ("smallholders"), 21% farmed between 51 and 1,000 ha, and only 2% managed more than 1,000 ha (Zeballos-Hurtado, 2011).

Figure 2. Primary area of soybean cultivation in Bolivia.
Source: Paz-Ybarnegaray and Fernández-Montaño (2009)

Soybean cultivation in Bolivia has developed almost exclusively in the Department of Santa Cruz de la Sierra, although some plantations are found in Tarija in the region of the Gran Chaco and O'Conor provinces, as well as in very small areas in Sucre (see Figure 2).

Today, 89% of soybean production in Bolivia takes place in Santa Cruz, where most of the producers are small-scale farmers, although the greatest share of the total harvest is grown on large-scale farms. In 2002, farmers in Santa Cruz harvested an estimated 96% of national soybean production (Zeballos-Hurtado, 2011). The Department of Santa Cruz has an established complex of businesses and institutions representing the agricultural sector, which is much more consolidated than the service networks found in other parts of the country.

Historically, agricultural production expanded in Santa Cruz purposefully, in a process known as "*La Marcha al Oriente*." Directed and semi-directed colonies (*colonias dirigidas*, *semi-dirigidas*) had total or partial support from the government, and spontaneous colonies (*colonias espontáneas*) followed. After 1950, these included Japanese colonies of Peruvian origin and colonies of Mennonites that settled during the late 1950s (United Nations Development Programme [UNDP], 2004). They are reported to have contributed actively to agricultural transformation in the region through the introduction of crop innovations and cooperative organization (UNDP, 2004). By 1980, 20% of the population in Santa Cruz was derived from directed colonies, and 70% was descended from spontaneous colonies.

Most studies of the Mennonite colonies in Bolivia (and these are few) are written in German and focus on the social characteristics of the colonies. A thesis by Lanning (1971) includes a translation from Spanish of the official Bolivian document granting Mennonites migration, granting them authorization to settle for the purpose of agricultural production, and protecting their rights to exemption from military duty, oaths, and external public administration, as well as custom duties for imports of machinery, utensils, seeds, animals, and implements necessary for their work. Based on his personal interviews with farmers, Lanning found little concern for the potential for soil degradation from intensive farming. Driven by a combination of religious beliefs and land constraints, the Old Colony Mennonites he studied migrated from Russia to Canada in 1890, from Canada to Mexico in 1922-1926, and onward to Bolivia beginning in 1967, primarily due to land constraints. He notes their shift from horse farming to machinery because of the need to cultivate larger areas to meet subsistence requirements. He describes their early approach to choice of crops, variety, and techniques as "hit or miss," citing one informant's declaration: "just wait until we learn how to farm here; then, we will really show people how to produce" (1972, p. 55). Cheap land prices and special treatment did not go unnoticed in the press; Lanning also includes a newspaper article questioning the benefits to Bolivia of Mennonite immigration and a rebuttal from the Department of Colonization.

Bolivia's Mennonites introduced soybean as a commercial crop and also play a particular role in the adoption of HT soybeans. Generally (in Santa Cruz), while their domestic lives are based on traditional technologies such as horse-drawn carts, the agricultural systems of Mennonites are mechanized, high-input systems and are comparable to the techniques used by industrial producers (Hecht, 2005). Multinational companies like Cargill and Archer Daniels Midland rely on their soybean and sunflower harvests to produce cooking oils and animal feed, and these exports have contributed to the prosperity of Mennonite landowners (Romero, 2006). Bender, Friesen, Ediger, Hiebert, and Mumaw (2010) estimate that Mennonites still grow roughly 75% of Bolivia's soybean crop in the Santa Cruz region.

Hecht (2005) reports official data from Santa Cruz that shows that, in addition to Mennonite farmers and some Japanese, Brazilian firms have purchased roughly 500,000 ha in Amazonian areas. Hecht describes the changing structure of soybean production—from 1990, when Bolivian nationals controlled about 42% and Mennonites and Japanese 57%; the mid-1990s, when Brazilians arrived; and 2000, when Brazilians controlled 31%. A "collection of nationalities including Russians, Canadians, and Finns" also represented 1% in 1990 and 8.5% of soy production by the end of 2001. By that time, Hecht concludes that most of the Bolivia soybean crop was grown by foreign producers and firms. In 2001 (the latest year for which data are available), the main language spoken by 23% of the population in Cuatro Cañadas—where the survey was conducted in the Department of Santa Cruz—was a foreign language (INE, 2011).

In February 2009, the new National Constitution of Bolivia was ratified, referring specifically to use of GMOs. Article 255 makes explicit reference to transgenic crops and their use, prohibiting the importation, production, or commercialization of GMOs and toxic elements that damage health and the environment. Article 409 states that the production, importation, and commercialization of transgenic crops will be regulated by law.

There is no available documentation of the exact date when HT soybean seed was first introduced in Bolivia. It is generally believed that the first HT seed was introduced from nearby Argentina and/or Brazil and tested initially by farmers in Santa Cruz near the end of the 1990s. The regulatory approval process for Monsanto's HT soybean began in 1998. Monsanto presented field trial results for RR soybean in February of that year, and in October, obligatory field trials were initiated. In November 2004, Bolivian authorities detected 400 ha of HT soybean in Santa Cruz and announced sanctions on commercial production. In 2005, the government of Bolivia authorized the production of HT soybean, as well as the production of seed, processing, and commercialization.

In 2006, a national government program to support the production of conventional soybeans was established (TCP-ALBA). The agreements of the program came into effect in April of that year in Havana, Cuba, by establishing that the Venezuelan government would create a financial fund to provide credit to Bolivians. The credit originates in a fund of US$100 million created by the government of Venezuela for the development of Bolivia, within the framework of the TCP-ALBA. The fund, managed through the Promotion and Development Bank (Banco de Fomento y Desarrollo [BFD]), was destined for four large programs, the first of which is of interest here.

According to Bolpress (2007), the first program (around US$25 million) encouraged the integrated development of small- and medium-scale soybean producers in the Departments of Santa Cruz, La Paz, Tarija, and Chuquisaca. The program envisaged a process of centralization, industrialization, and commercialization to generate added value and employment in rural areas. Registered small- and medium-scale producers or organizations could obtain credit at an annual interest rate of 4% to expand their production activities.

In the *municipio* of Cuatro Cañadas, the Integrated Community Producers Association of Cuatro Cañadas (Asociación Comunitaria Integral de Productores Agropecuarios de Cuatro Cañadas [ACIPACC]) benefited from a part of the funds received during the 2007 season. According to the Minister of Rural Development at that time (Susana Rivera), the program sought to establish an alternative funding system to the conventional system. The conventional system is perceived to favor agroindustrial firms and commercial enterprises and appeared to be disadvantageous for smallholder soybean producers because it is said to have offered them overpriced inputs, discriminated against them in grain purchases, and engaged in harvest price speculation (Bolpress, 2007).

The *municipios* of San Julián and Cuatro Cañadas, where small-scale producers of soybeans are concentrated, are home to supporters of the Movimiento al Socialismo (MAS), the party that governs Bolivia. Within the Agricultural Development Plan, the national government launched a program that provided credit for production and commercialization by small-scale producers of conventional, but not transgenic, soybeans. This program began during the year of the survey. In legitimate defense of their interests, smallholder soybean producers of San Julián, in particular, were not favorably disposed to discussions about HT soybeans.

Methods

In interpreting the data collected in 2007-2008, and how it was collected, several factors are important to bear in mind. The first is the general political opposition to the cultivation of HT soybeans. The second is that the government endorsed and financially supported the production of conventional soybeans, which compete with HT soybeans. The third is the particularly poor weather situation in the year of the survey, which in turn contributed to higher soybean prices. In addition to these factors, the study team had a constrained project budget and scant prior information on which to base a probability sample. Sampling considerations are described next.

A total of 129 households were interviewed, including 109 in 19 communities of smallholder producers (13.5% of a total estimated population of 813) and 20 in four communities of smallholder Mennonite producers

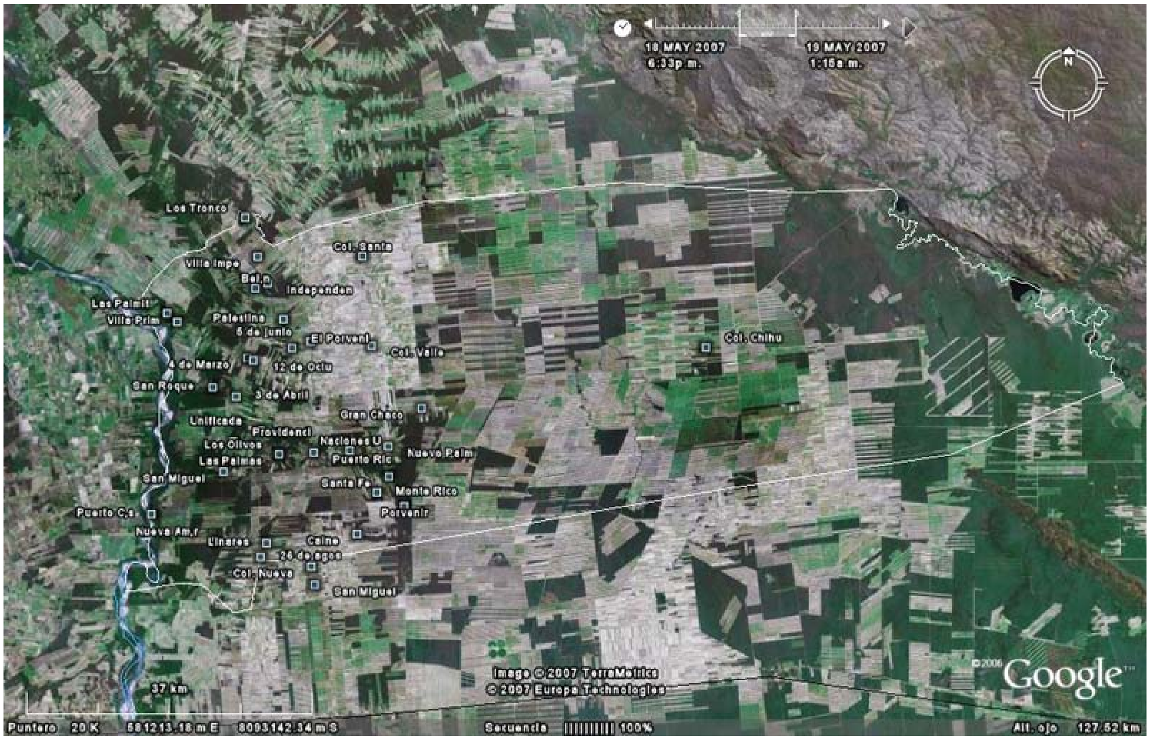

Figure 3. View of the *municipio* of Cuatro Cañadas, Department of Santa Cruz, Bolivia.
Source: Paz-Ybarnegaray and Fernández-Montaño (2009)

(3.8% of a total estimated population of 525). Authorization was obtained from community leaders to interview households in Mennonite communities.

Sampling and Survey Implementation

Designing a sampling frame for the study was the first challenge faced by the team. The characteristics of small-scale soybean farmers have not been documented in Bolivia, and no information was systematically collected on their numbers or the distribution of their landholding size at the time of the survey. Furthermore, no official data were available concerning the amount of transgenic soybean produced in Santa Cruz or how it was geographically distributed. Some estimates suggested that 70% of soybean production in Santa Cruz during the 2006-07 season was transgenic. Medium- and large-scale farms reportedly grew almost exclusively transgenic soybean. Although it was known that small-scale soybean producers also grew HT soybean, their dispersion in various zones of production made it difficult to estimate adoption rates and their variation. Nonetheless, the team knew that the two *municipios* with the highest concentration of small-scale soybean producers were San Julián and Cuatro Cañadas. Both are zones of colonization. Given the political situation noted above, which was confirmed during field visits that preceded the sample survey, the team selected the *municipio* of Cuatro Cañadas for the sample survey.

Purposively selected, the *municipio* de Cuatro Cañadas de Santa Cruz de la Sierra is emblematic of the social and economic structure of soybean production in Bolivia. Figure 3 shows an aerial view of the study area, with spontaneous colonies represented by star-shaped formations and directed colonies shown as parallel field patterns.

Following the selection of the *municipio* of Cuatro Cañadas, the team consulted the list of 43 communities identified by the Instituto Nacional de Estadistica (National Statistics Institute) of 2001. This secondary information, while useful, was insufficient to develop a typology of communities from which a representative sample could be drawn—specifically with respect to small-scale producers of HT soybeans. The team then visited all communities. By community, they obtained the name and type of community, the number of families and total area cropped, the amount of land originally distributed per family, whether HT soybean was produced, and geographical reference data. Of 43 communities, a large number were excluded because they a) no

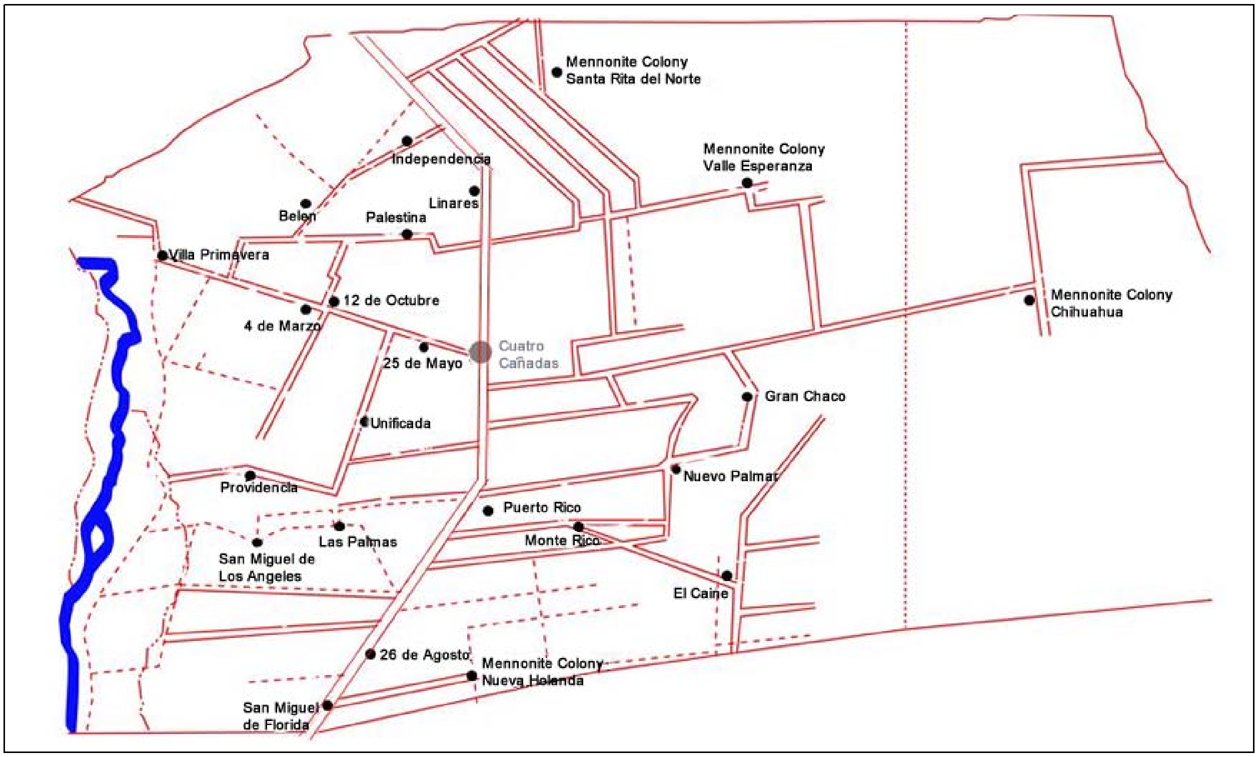

Figure 4. Mapping of communities in the *municipio* of Cuatro Cañadas, Bolivia.
Source: Paz-Ybarnegaray and Fernández-Montaño (2009)

longer existed; b) focused on livestock production, fishing ,or hunting; c) did not include smallholders; d) were urban; or e) had leaders who refused to participate.

The team then selected those communities with less than 50 ha originally distributed per family and current average hectares per family under 50; this resulted in a sample of 23 communities. Each of the 23 communities was then revisited to obtain the names and numbers of soybean producers.

The sample is probabilistically representative of smallholder soybean producers in communities within the *municipio* of Cuatro Cañadas whose leaders are willing to participate in the survey and producers who grow at least some transgenic soybean. The findings can be generalized only to the extent that these criteria, and the characteristics of farmers surveyed, match those in other *municipios* of Santa Cruz.

In order to select households in communities, the team initially sought to employ a geographically-based random selection of farms based on location in a grid map. Since no map or list of farms was available with (or made available by) local community leaders, this was accomplished through a rapid physical census in the community. The process was made more difficult (and costly) by the varying settlement patterns and relatively large farm sizes. The general mapping of the communities is shown in Figure 4.

In addition, locating farmers posed challenges. Many reside elsewhere during most of the year, returning to the fields only for key production and harvesting activities. To elicit yield estimates, it was necessary to conduct the survey during the harvest season. At that time, even when found, farm families were pressed for time. This means that potential biases are associated with whether or not the farmer was present in the fields at the time of the survey. Among farmers surveyed, 87% resided in the community most of the year, 10% resided in Cuatro Cañadas, and only 3% lived outside Santa Cruz.

A total of 129 questionnaires were implemented in 14 days in three trips. Thus, although our findings are based on probability sampling from a carefully selected domain of small-scale producers, we have had to exclude communities because of political considerations and were not able to follow a treatment design by prestratifying households and communities according to adoption. In addition, enumerators had to overcome farmer mistrust, and farmers were interviewed under duress. These limitations should be recognized in interpreting our findings.

Hypotheses

Three hypotheses drove this research. The first is that social relationships shaped the way the seed of HT soybeans and information about the seed travel among smallholder farmers in Bolivia. Here, Bolivia is a special case because transgenic seed appears to have been introduced by farmers before formal release by the government. The second, which is a selling point of those who favor its use, is that growing HT soybeans reduces the use of more toxic chemicals. The third, demonstrated by studies conducted in the United States, is that growing HT soybeans enables farm households to reallocate family labor to other income-generating pursuits.

Statistical Approaches

To explore the relationship of HT soybean use and social networks, we applied NETDRAW, a free social-network analysis software, to depict sources of seed and seed-related information.[3] We compared expenditures on herbicides at the mean between HT growers and non-HT growers, but also the frequency distributions, according to toxicity.

To measure the impact of the HT crop on labor, household labor use, and off-farm income with an econometric model, we a) applied a control function approach, b) tested and controlled for the endogeneity of HT use, and c) tested specifically for selection bias. There are several reasons why we chose this strategy, among other options.

Ideally, a randomized experiment of adopters and non-adopters would have been preferred in order to estimate the adoption, but a design of this type was not feasible in Bolivian communities at the time of this study. Our sample is too small to employ the quasi-experimental technique of propensity score matching (PSM), which would have allowed us to match adopters and non-adopters based on their observable characteristics and then calculate impacts of adoption among similar households (Ali & Abdulai, 2010). Also, in comparing experimental and quasi-experimental methods, Handa and Maluccio (2010) concluded that PSM techniques perform better for easily measured outcomes such as those related to child schooling and health than for more complex outcomes such as expenditures or income. Our outcomes are complex.

A relatively simple way to control for the unobserved characteristics that can explain both why a farmer uses HT soybeans and the impacts of using them is to analyze plot-level differences for partial adopters while controlling for the land quality of plots. While useful for estimating effects of adoption on plot-level variables such as yield, input use, and costs, we were also interested here in impacts on household labor use. Furthermore, we found few partial adopters. The final sample of households included 49 growers of only conventional soybeans, 72 growers of only transgenic soybeans, and 7 growers of both (partial adopters). We could not pursue this option.

With a larger research budget and a less sensitive topic, the team might have visited a greater number of communities in more than one *municipio* where HT soybeans were/were not grown, listed all soybean growers within the communities, and selected adopters and non-adopters in adopting villages as well as non-adopters in non-adopting villages. This technique would have constituted a "treatment-control" design, enabling us to control for both observable and non-observable characteristics of farmers and estimate the local average treatment effect with instrumental variables regression (Angrist & Krueger, 2001; Ravallion, 2005). Instead, the team was obliged to "search" for HT soybean growers in soybean-growing communities, and adopters and non-adopters can be compared only on observed characteristics.[4]

Instrumental variables regression—in which exogenous variables explain adoption but do not affect outcome variables—is a common means of removing selection bias from impact estimates (Angrist & Krueger, 2001; Ravallion, 2005). Heckman-type models can be used to control for selection effects, but rely on normality assumptions for identification. Two-stage least squares, which relies on the central limit theorem, is considered to be robust; even with a dummy endogenous variable, second-stage estimates are consistent (Kelejian, 1971).

Our three outcome variables include corner solutions at zero: 1) total household off-farm income, 2) off-farm days worked by household member who contributed most, and 3) second-to-most soybean production during the soybean growing season. Instrumental variables Tobit with a discrete endogenous variable is not recommended because it implies that in the second stage, a nonlinear function of an endogenous variable is

3. *See http://www.analytictech.com/Netdraw/netdraw.htm.*

4. *Today, if the estimates of 92% adoption rates reported by ANAPO (Zeballos-Hurtado, 2011) are correct, it may be difficult to find communities without HT growers.*

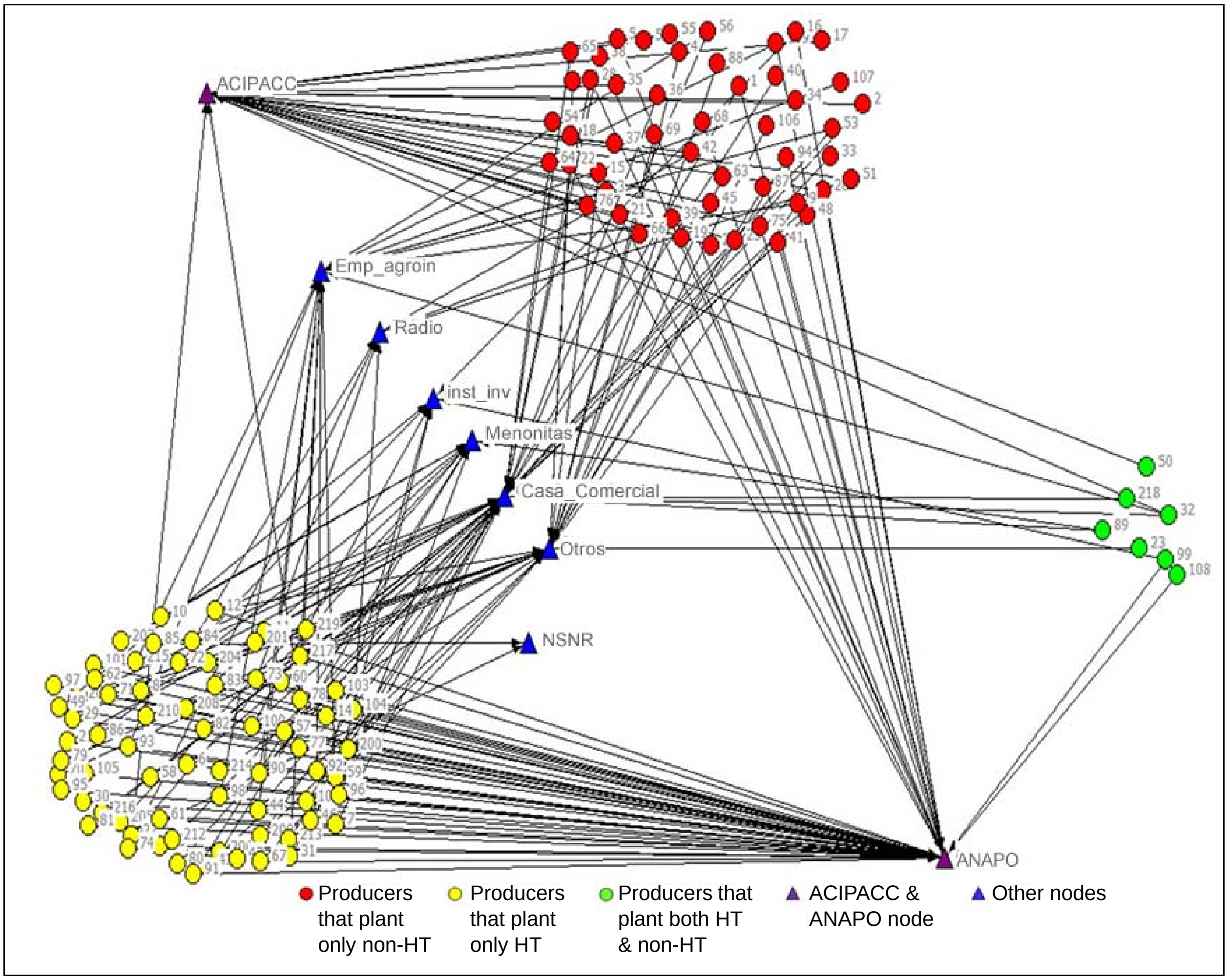

Figure 5. NETDRAW map of information sources about soybean seed, HT and non-HT growers.
Source: Paz-Ybarnegaray and Fernández-Montaño (2009)

replaced with the same nonlinear function of fitted values from a first-stage estimation (Wooldridge, 2002).

The control function approach enables us to account and test the endogeneity or self-selection bias in a nonlinear model such as the Tobit when the potentially endogenous variable is binary. As in a two-stage instrumental variables model, the control function approach requires an instrumental variable to be used in the first stage. In the second stage, however, the structural model is estimated with the observed endogenous variable and the residual from the first stage as explanatory variables. The test of endogeneity is the statistical significance of the coefficient of the residual, estimated with bootstrapped standard errors. The control function approach is described in early work by Blundell and Smith (1989).

Shankar and Thirtle (2005) and Mutuc, Rejesus, and Yorobe (2011) test for both endogeneity and selectivity in their estimation of the impacts of Bt maize adoption. These authors were concerned about endogeneity of pesticide use and the sample selectivity of adoption, which represent two distinct sources of inconsistency or bias (if understood as special forms of an omitted variable problem). We follow their approach by also testing the significance of the Inverse Mills Ratio (IMR) in the second-stage regressions on both sub-samples of adopters and non-adopters.

Explanatory variables in all regression stages are the year of arrival in the community (indicating the type of colony and ethnicity), whether the farmer was Mennonite, the average education of adults in the household, the number of adults in the household, the number of adolescents in the household, and whether the family

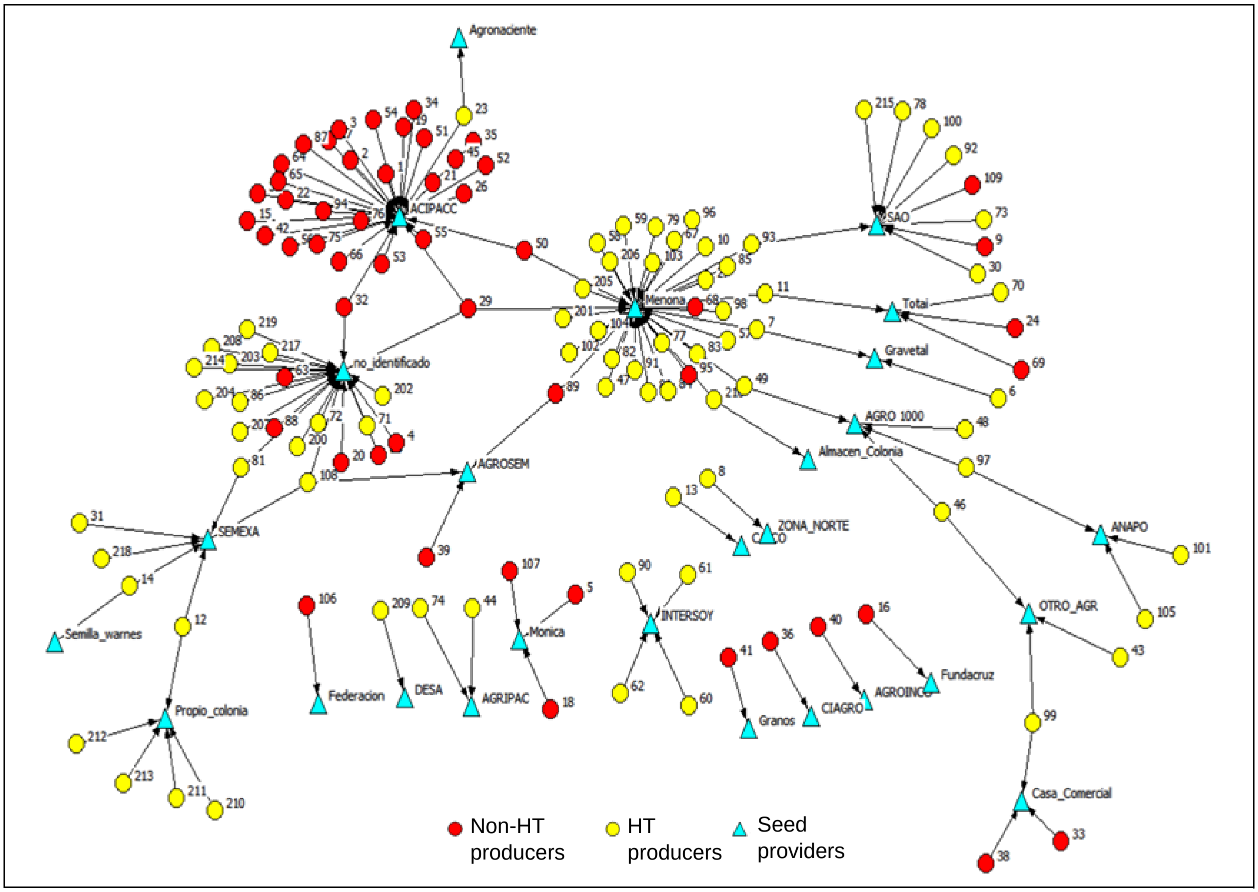

Figure 6. NETDRAW map of seed sources, HT and non-HT users.
Source: Paz-Ybarnegaray and Fernández-Montaño (2009)

lives on the farm. Instruments for identifying the impact of adoption on outcome variables are the average share of soybeans in cultivated land over the 2007-08 seasons, the seed-to-product price ratio, and whether or not the farmer owns all machinery for soybean production.

Findings

Counting partial adopters as adopters, 61% of households surveyed grew HT soybeans in the summer season of 2007-08. Survey data indicate that adopters have larger soybean areas (67 as compared to 30 ha on average), more educated adults (7 as compared to 6 years of schooling, on average), and are more likely to own farm machinery (tractors, planters, sprayers, harvesters). They are more likely to own their farm—or a means of transport (car or truck)—but not cattle or sheep. Thus, as expected, HT adopters appear to be more well-endowed in terms of various forms of physical capital.

Networks by sources of seed and seed-related information are shown in Figures 5 and 6. In both figures, colored circles represent smallholder producers, and triangles represent persons, groups, or institutions that supply information; lines refer to the information itself.

Sources of information bifurcate strongly according to seed type. Figure 6 shows the accumulation of the sample farmers around two institutions as principal sources of information. Non-HT users (red circles) are more likely to receive seed information from ACIPACC, and users of HT soybeans (yellow circles) are grouped around the ANAPO. The 20 Mennonite farmers surveyed "self-cited" as information sources, referring to their own communities as the primary source of information. Mennonites are a source of information only regarding HT seed. Partial adopters appear to have cited both sources of information. Radio is not an important source of information for any of the farmers interviewed, but commercial establishments (*casas comerciales*) are important for both types.

Differences between adopters and non-adopters with respect to the number of sources of information (1.5 for HT-users, 1.6 for non-HT users) are not statistically significant. Both groups tend to rely on more than one source. Of course, ANAPO provides information about both types of technology, but ACIPACC supports only non-HT seed. Despite this fact, 24% of HT users reported little or no confidence in the information provided by ANAPO. Among non-HT users, this percentage is as high as 31%, while only 10% reported that they did not trust the information from ACIPACC. Overall, those actors cited as having the complete confidence of growers are ANAPO (50%) for HT users, ACIPACC (60%) among non-HT users, and commercial establishments (43%) among HT users (only 12% among non-HT users; Paz-Ybarnegaray & Fernández-Montaño, 2009).

Seed sources display a different configuration of social networks (see Figure 6). Seed sources are highly dispersed and individualized, with few nodes linked to multiple farmers and many nodes linked to few. Three sources are foci: Mennonites, ACIPACC, and unidentified. The remainder of seed sources are numerous and marginal in terms of representation. HT users obtained seed primarily from Mennonites, and non-HT users relied principally on ACIPACC, where they have acquired the variety Uirapuru. Uirapuru is a well-known variety that was furnished on credit as part of a technical package.

The partial budget estimated from survey data is shown in Table 1, based on information recorded for one plot per farmer. Yields are higher on HT than for non-HT plots, and higher prices for non-HT soybeans (reflecting preferential policies) are not sufficient to dampen the higher gross benefits and net benefits received by HT soybean growers. Variable input costs do not differ significantly between the two groups, aside from the category “other labor costs” (costs of labor for land preparation, planting, and harvest), which is lower from HT growers. This finding suggests that, as elsewhere in the world where HT soybeans have been commercialized, land preparation demands less labor and is more likely to be planted under zero or minimum tillage (see, for example, Fernandez-Cornejo & Caswell, 2006).

As explained in the section about counterfactuals, and the evidence shown in Table 1, these results, although indicative, should be interpreted with caution given the potential for selection bias. That is, HT growers may be better managers, and be more well-endowed than non-HT growers regardless of whether they grow HT soybeans.

Table 1. Partial budget for non-HT and HT soybean growers in Bolivia 2007-2008.

	Non-HT	HT
Yield (t/ha) *	1.47	1.91
Price (US$/t) *	409.32	398.59
Gross benefit (US$/ha) *	600.26	780.83
Costs (US$/ha)		
Seed	23.46	26.78
Herbicides	41.53	32.25
Labor, chemicals	4.98	5.03
All other labor costs *	3.50	2.25
All other variable costs	114.29	114.11
Net Benefits (US$/ha) *	412.50	600.41
HT- non-HT (US$/ha) *		187.91

Source: Paz-Ybarnegaray & Fernández-Montaño (2009)
(*) difference in means between groups significant at 5% with two-tailed t-test.

When herbicides are grouped according to the World Health Organization [WHO] guidelines classification of pesticides by hazard (World Health Organization, 2010), 73% of all herbicides used by HT growers in 2007/2008 are classified as unlikely to present hazard. In comparison, only 52% of herbicides applied by non-adopters fall into this category. One-quarter of all herbicides used by non-adopters are moderately hazardous, and 22% are slightly hazardous. None of the herbicides used by either group were among the most toxic (Table 2).

The proportion of families living on the farm did not differ significantly based on whether the family grew HT soybeans. An average of 86% lived on the farm. Table 3 includes estimates of mean numbers of family members involved in various aspects of soybean production. The numbers indicate, in a general way, that adult men are the most involved in production, but that all members of the household, including children, participate in some activities. Across all activities, adult females appear to number about half the number of adult males.

With respect to our working hypothesis concerning labor, 76% of HT users reported that the amount of time spent by family labor on soybean production declined with adoption, and another 18% reported that it remained the same. Complementary to this point, 80% of HT users perceived that managing soybean production is easier when HT soybeans are grown, and 9% stated there was no change. Nearly one-third of non-HT users also perceived that growing HT soybeans was eas-

Table 2. Herbicides used by hazard classification, non-HT users, and HT users.

	WHO classification of pesticide by hazard (%)*					
	Ia	Ib	II	III		
Herbicides	Extremely hazardous	Hazardous	Moderately hazardous	Slightly hazardous	Unlikely to present acute hazard	Total
Non HT-users	0.0	0.0	24.6	22.2	51.6	100
HT users	0.0	0.5	13.1	13.1	73.3	100

Source: Paz-Ybarnegaray & Fernández-Montaño (2009)

(*) Chi-squared test shows differences in distributions at 5% level of significance.

Table 3. Family labor use in soybean production, by task, age, and gender.

		Mean number of persons working in soybean production					
		Land preparation	Planting	Cultivating	Harvest	Sales	All activities
Male	Children	0.10	0.16	0.18	0.10	0.04	0.04
	Adolescents	0.49	0.63	0.64	0.51	0.36	0.36
	Adults	0.85	0.85	0.86	0.83	0.76	0.76
	Sub-total	0.59	0.63	0.64	0.58	0.50	0.50
Female	Children	0.07	0.09	0.11	0.13	0.02	0.02
	Adolescents	0.20	0.16	0.25	0.13	0.09	0.09
	Adults	0.46	0.59	0.60	0.53	0.36	0.36
	Sub-total	0.31	0.38	0.40	0.34	0.22	0.22
All family members		0.47	0.52	0.54	0.48	0.38	0.38

Number of households interviewed=129; Source: Authors based on survey data.

ier. Nearly all HT users (96%) perceived that management of targeted weeds was easier than with non-HT seed, and 60% reported no differences with respect to other soybean pests and diseases.

The research team asked which individual in the household was considered to be the primary soybean decision-maker, and which two individuals spent the most time in soybean production. In all but two cases, the primary decision-maker was also the head of household. The head of household was also typically the person who contributed most to soybean production. Apart from the head of household, the members who contributed the most to soybean production were most often the spouse or children of the head. The research team attempted to elicit days worked by type of activity for the two key contributors. Table 4 shows that the estimated number of days worked by these individuals did not differ significantly between non-HT and HT users, with the exception of off-farm work, which was greater for the second major contributor among HT users. As a consequence of the second major contributor, total days worked off-farm in the summer season differs significantly between non-HT and HT users.

Statistical differences by income source are pronounced between HT adopters and non-adopters. Soybean income, as well as off-farm income and total household income, is substantially higher for adopters,

Table 4. Days worked by type of activity during the summer season, non-HT and HT users.

	Non-HT	HT	All
Household member 1			
Soybean production	37.8	41.4	40.0
	2.9	2.7	1.9
Other on-farm work	50.0	45.6	47.3
	6.4	4.5	3.6
Off-farm work	16.5	22.2	20.0
	4.3	4.1	3.0
Household member 2			
Soybean production	27.3	36.4	32.6
	3.8	6.4	4.0
Other on-farm work	63.3	53.4	57.6
	8.1	6.6	5.1
Off-farm work *	10.8	24.2	18.5
	4.6	5.1	3.6
Total off-farm work *	27.3	46.3	38.5
	6.2	7.2	4.9

Source: Authors, based on survey data.

Note: Means (s.e.). (*) difference in means between groups significant at 5% with two-tailed t-test.

Table 5. Income by source during the summer season, non-HT and HT users.

Income source	Non-HT	HT	All
Soybeans *	12,524	46,944	33,559
	1,838	4,833	3,381
Crops other than soybeans	903	1,374	1,191
	816	542	457
Livestock	517	581	556
	84	17	100
Off-farm income *	228	1,940	1,274
	76	434	277
Total household income *	14,172	50,840	36,580
	1,966	4,977	3,512

Source: Authors, based on survey data.
Currency=Bolivianos; Means (s.e.)
Note: Means (s.e.) (*) difference in means between groups significant at 5% with two-tailed t-test

although income from other crops and livestock do not differ significantly at the mean (Table 5).

The findings in Tables 4 and 5 support the hypothesis that growing HT soybeans is associated with greater off-farm labor by the main soybean contributors in the household, reflecting in particular the off-farm labor of the spouse or adult child. More off-farm labor is reflected in greater off-farm earnings.

Results of the first-stage, reduced-form probit regression are presented in Table 6. More recent colonizers are more likely to grow HT soybeans. The binary variable for Mennonite farmers was omitted due to perfect prediction of adoption in 20 cases. Ownership of all machinery for growing soybeans has a strong and positive effect on adoption of HT soybean. Household labor supply and living on the farm are not significantly associated with adoption, although higher average education among adults contributes positively to growing HT soybeans. Finally, paying a higher ratio of seed to product price is associated with adoption, consistent with the fact that non-conventional growers receive subsidies and a higher product price.

Tobit regression of off-farm income during the growing season on explanatory variables, HT use, and the residual from the first-stage regression results in failure to reject the hypothesis that adoption is endogenous (p-value of 0.04 on the coefficient of the residual). The same regression estimated on the sub-sample of adopters and non-adopters and including the IMR from the first-stage Heckman model shows statistical significance of selectivity bias in each case. However, both the residual and IMR cannot be included in the same regression because they are collinear. We conclude that they capture a similar effect, and present the structural model with the residual in the first panel of Table 7.

Table 6. First-stage, reduced form probit regression explaining HT soybean adoption.

	Average partial effect (dydx)	Delta-method Std. err.	P>z
Year of arrival	-0.063	0.027	0.020
Mennonite	(omitted)		
Live on farm	0.551	0.408	0.177
Average education of adults	0.124	0.051	0.015
Adults >18 years	-0.003	0.101	0.972
Teens 11-17 years	-0.082	0.129	0.528
Mean soybean % of total land (2007-08)	0.010	0.564	0.986
Soybean machinery	0.265	0.093	0.004
Seed to product price	1.239	0.669	0.064
Constant	123.100	53.900	0.022
N		105	
LR chi^2(6)		30.80	
Prob > chi^2		0.0000	
Log likelihood		-57.145414	

Source: Authors, based on survey data.

Use of HT soybeans is associated strongly with off-farm income (Table 8), increasing it by more than 9,000 Bolivianos. This important result does not change when errors are bootstrapped. The marginal effect of an additional working-age adult is positive, but the effect of adult education appears to be negative. Living on the farm has a powerful offsetting effect, reducing off-farm income by an average of 3,113 Bolivianos. However, bootstrapping reduces much of the statistical significance of these variables.

The structural regression estimating the impact of adoption on days worked off-farm by Soybean Contributor #1 was statistically insignificant. In the case of Soybean Contributor #2, the IMR was statistically significant in only one of the two sub-sample regressions, and the residual was not significant (p=0.23). The final Tobit regression, with HT use entered as an exogenous variable, is shown in the second panel of Table 7. Again, HT soybean adoption is positively associated with more off-farm work by Contributor #2, as is the number of adults on the farm. Living on the farm detracts from time spent in off-farm activities.

Table 7. Second-stage Tobit regression explaining off-farm household income and number of days worked off-farm by Contributor #2 during soybean growing season.

	Off-farm income			No. days off-farm		
	dydx	Delta std. err.	P>t	dydx	Delta std. err.	P>t
HT soybean adoption	9,082.3260	2,957.2040	0.003	66.3780	27.4880	0.018
Year of arrival	142.4790	129.4878	0.274	2.4530	2.0990	0.245
Average education of adults	-400.8240	231.8151	0.087	-4.7310	4.2750	0.271
Adults >18 years	665.2723	398.7993	0.099	19.3640	8.2560	0.021
Teens 11-17 years	357.2272	507.2177	0.483	-2.7510	10.2910	0.790
Live on farm	-3,113.3900	1,604.2890	0.055	-79.0190	31.2150	0.013
Residual from Stage 1	-6,748.2900	3,168.6360	0.036			
Constant	-286,838	257,904	0.269	-4,936.8980	4,178.3270	0.240
N		102			105	
LR chi^2		(7) = 20.35			(6) = 13.65	
Prob > chi^2		0.0049			0.0092	
Log likelihood		-473.09			-202.80	

Source: Authors, based on survey data.

Conclusions

Despite the overtly anti-GM perspective of the Bolivian government, as well as subsidies designed to encourage production on non-HT soybeans, Bolivian farmers introduced and diffused HT soybeans largely on their own. Santa Cruz, the primary soybean-growing region of Bolivia (and our region of study), has been colonized in differentiated ways, and these patterns are related to ethnicity and farming system.

Following findings reported in previously published literature about the impacts of HT soybeans, the research team hypothesized that HT soybeans reduce use of toxic herbicides and enable farm families to save on management time and reallocate labor to other income-earning activities. The introduction of HT soybeans by farmers themselves led us to hypothesize that social networks played a large role in the diffusion of seed and seed-related information.

Data indicate that while expenditures on herbicides do not differ at the mean between HT and non-HT soybean growers, non-HT soybean growers use herbicides that are distributed towards higher toxicity levels.

Application of a free social-network analysis package revealed that at least during the time of this survey, Mennonite farmers were an important focal point and conduit for HT soybean seed. Seed information sources are concentrated but bifurcated around the national producers' association and the association that subsidized non-HT soybean production. Seed sources are highly dispersed and individualized, with few nodes linked to multiple farmers and many nodes linked to few.

Indeed, growers of HT soybeans have more of several types of important assets, more land, and more educated adults. Estimation of a control function approach enabled us to test the endogeneity as well as the selection bias of adoption in off-farm income and off-farm labor days of the two adults who contributed most to soybean production during the survey season. 'More recent arrival in the area,' 'whether the farmer is Mennonite,' 'more educated adults,' 'owing machinery for soybean production,' 'seed-to-product price ratio,' and 'living on the farm' are all positively associated with HT use. Through adoption, these factors are also associated with off-farm income. Adoption has a large, important effect on off-farm income earned by the household during the soybean growing season. One striking result is that the off-farm work associated with HT adoption is that of the second major contributor to soybean production, rather than that of the first. Most of these are wives of the household head, followed by sons and daughters.

Methodological Challenges

The survey team encountered major challenges associated with lack of information about the extent of adoption and location of adopters, political sensitivities and mistrust in study communities, a common practice of living off the farm, and exceptional weather conditions for two seasons. Several rounds of household listing were required, and enumerators were obliged to interview respondents during the harvest.

We recommend that in countries where early-adopter surveys are conducted, researchers dedicate a substantial share of budget and time to developing a sampling frame that can be used in multiple rounds of panel surveys. Doing so may require the participation of a statistical expert. The design should be fully documented and the frame made public. A second recommendation is to undertake the design of monitoring and evaluation studies via a research consortium or consultation group rather than a single organization. The consultation group, in particular, might be established in order to provide a forum for the range of stakeholders involved in GMO decision-making to discuss the design as well as the findings. This type of approach seems promising as a means to overcome the heightened sensitivities associated with field research on GM crops. We originally intended to develop this approach, but our budget was too limited to support it.

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