Chapter 5

Assessing Genetically Modified Cotton's Economic Impact on Farmers

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In Uganda, cotton has been characterized as a crop with relatively low profitability, mostly due to low productivity (Baffes 2009), but also because it is affected by fluctuations in cotton's world price. Studies done by APSEC (1998, 2001) ranked cotton as the lowest in profitability among the main competing crops on the global market. Despite cotton's low profitability, farmers continue to plant it. The most-often-cited reason for continued cotton production is a lack of productive alternatives that can generate cash for smallholders and larger farmers during the period cotton is planted. The certainty that cotton producers will have a buyer at the end of the season is probably another strong argument for cotton cultivation: ginneries usually distribute seed and inputs and in turn demand rights over the seed cotton harvest at the end of the cropping season.

In this chapter, the following question is addressed: would the adoption of genetically modified (GM) cotton make farmers better off? The methods and tools chosen to address this question had to be adjusted to the Uganda context, where biosafety regulations are in the process of approval and the inclusion of socioeconomic considerations is expected to contribute to decisionmaking. To produce meaningful results within a limited time and a restricted budget is challenging. It is also challenging to produce these results for a technology that has not been tested in the country. That GM cotton is a technology already approved in about 10 countries, including South Africa and Burkina Faso, does make the task easier, however.

In this study, the primary data comes from the household survey implemented in the two main cotton-producing districts in Uganda: Kasese and Lira. Secondary sources are also used, especially to support assumptions that the selected methodological approach demands. The study evaluates yield performance by using a production function to understand factors determining productivity. Partial budgets are used to evaluate the profitability of cotton production at the farm level and to compare conventional production with hypothetical GM crop scenarios. The study adds stochastic simulations to the partial budgets to account for the effects of risk and uncertainty related to cotton production and its profitability. Although the sampling framework for the collection of primary information does not permit the extension of findings to the country level, this exercise does allow a more detailed understanding of what the impact of GM cotton adoption could be on farmers in the most important cotton districts in Uganda.

Measuring Ex Ante Impact of GM Technologies on Farmers

Although an economic literature exists on the impact of transgenic crops on farmers' welfare, most of these evaluations are ex post (Smale, Niane, and Zambrano 2010). Two main approaches have been used to measure this ex post impact: (1) examining partial budgets that compare net profits from adopters and nonadopters and (2) using a statistical approach in an economics framework, such as a production function or a random utility framework. Even though the second approach allows for a more rigorous test of ex post impact (Smale et al. 2009), the use of econometric tools is more limited in ex ante evaluations, especially in those cases where there is no experimental or trial information that can be analyzed.

There are, however, a few examples of studies that use econometric tools to evaluate farmers' preferences and thus potential adoption of GM crops. Edmeades and Smale (2006) predict farmer demand for disease- and pest-resistant bananas in the East African highlands using a trait-based model and survey data that detail cultivar attributes and the characteristics of farmers, households, and markets. Kolady and Lesser (2006, 2008a,b, 2009) and Krishna and Qaim (2007) explore ex ante the potential adoption and impact of insect-resistant eggplant in India using contingent valuation, production functions, partial budgets, and sensitivity analysis to assess the potential benefits of the adoption of open-pollinated varieties versus hybrids. Birol, Villalba, and Smale (2008) and Kikulwe et al. (2009) examine farmers' preferences and use a latent class model to identify the characteristics of future GM seed adopters. In the first case, the authors characterize farmers and their need for compensation if transgenic maize were introduced to Mexico. In the second case, the authors assess the case of transgenic banana in Uganda.

Although these studies are very important resources for GM crop evaluation, the research question they address—how farmers' preferences affect GM crop adoption—is slightly different from the one addressed in this chapter: how profitable is GM crop adoption? If decisionmakers in a country opt to include socioeconomic considerations in biosafety regulation approval, they would be interested to know whether the adoption of GM crops results in a profitable business. With this objective in mind, the use of partial budgets at the farm level is the preferred option. Partial budget analysis is a simple tool that can assist in understanding cotton profitability and identifying some general constraints on profits. This tool is particularly useful for re-creating farmers' actual conditions and simulating counterfactual scenarios. A common criticism of partial budgets, however, is that they are only snapshots of reality. The use of stochastic simulations in addition to partial budget analyses allows for a more dynamic analysis that can better represent farmers' conditions. This representation of farmer conditions also distinguishes this study from early studies of GM varieties that were only ex ante studies or field experiments (Qaim and Zilberman 2003).

Methodology

To assess the potential impact on farmers of GM seed introduction, we first analyzed the effect of risk and uncertainty on the current performance and profitability of cotton production. We consider this step necessary not only to find out what the main yield determinants are but also to gauge the use of chemical inputs and their effectiveness in controlling the target constraints (bollworm and weeds). This information is crucial for developing scenarios and simulations. As much as possible, we use primary data to determine our assumptions about GM technology's performance. Table 5.1 presents the methodological steps followed and the data used for this assessment.

Production Function

The use of a production function to evaluate the performance of a technology ex ante is possible only if there is at least trial data available. However, this is not the case for GM cotton in Uganda, as the GM technology has not yet been deployed. Nevertheless, an assessment of cotton production can help evaluate the main factors determining crop performance and determine the possible effects of introducing GM seed (as done by Horna et al. 2008).

Our study uses a production function with a damage-control framework to correctly account for the effect on yield of inputs that facilitate growth and control damage. The damage-control framework (Lichtenberg and Zilberman 1986) has been widely used to measure the ex post impact of growing Bt cotton (Huang et al. 2002a,b; Qaim and de Janvry 2005; Shankar and Thirtle

TABLE 5.1 Methodological steps

Step	Method	Data source
1. Evaluate current yield determinants of cotton	Production function using a damage-control framework	Survey data
2. Estimate current profitability, risk, and uncertainty of cotton production systems (conventional and organic)	Partial budget analysis Stochastic simulations of conventional and organic cotton production	Survey data and assumptions about GM technology performance Simulated distributions based on survey data
3. Forecast cotton profitability with GM seed introduction	Stochastic simulations of cotton production using GM seed (Bt and HT)	Simulated distributions based on (i) survey data and (ii) assumptions about GM technology performance
4. Analyze GM seed introduction's impact on farmers, given different payment arrangements for the technology fee	Stochastic simulations of cotton production using GM seed (Bt and HT)	Simulated distributions based on (i) survey data, (ii) assumptions about GM technology performance, and (iii) assumptions about potential technology fees
5. Evaluate the effect of complementary inputs: labor, fertilizer, and pesticides	Sensitivity analysis	Assumptions based on best available information

Source: Authors.

Note: Bt = insect resistant; GM = genetically modified; HT = herbicide tolerant.

2005). As explained by previous studies' authors, the damage-control framework considers that agricultural inputs, such as insecticides and pesticides, are not yield enhancing but loss abating. The damage-control effect is defined as the proportion of the destructive capacity of the damaging agent that is eliminated by applying a certain amount of a control input. Control inputs can be pesticides, additional labor, cultural practices, a crop variety (including a GM variety), or any other input that the farmer uses to mitigate the impact of pests and diseases. A standard production function in a damage-control framework is specified as

$$Y = F\left[\mathbf{Z}, G(\mathbf{X})\right], \tag{5.1}$$

where Y is the crop output, the vector $\mathbf{Z}$ represents directly productive inputs, and the vector $\mathbf{X}$ represents the control inputs (Lichtenberg and Zilberman 1986). The damage-control function $G(\mathbf{X})$ takes values in the interval [0, 1]. If there is no control of the damage, $G(\mathbf{X}) = 0$ and $Y = F[\mathbf{Z}, 0]$; if there is complete control of the damage, $G(\mathbf{X}) = 1$ and $Y = F[\mathbf{Z}, 1]$. In this equation, even though the function $G(\mathbf{X})$ is unobservable, the use of control agents $\mathbf{X}$ can be directly observed and measured.

For a flexible and robust estimation of cotton production in Uganda, this study used a quadratic production function with a logistic abatement function:

$$Y = (\alpha + \sum_i \beta_i \mathbf{Z}_i + \sum_i \sum_j \phi_{ij} \mathbf{Z}_i \mathbf{Z}_j + \gamma \mathbf{H} + \varepsilon) \times ([1 + \exp(\mu - \sigma \mathbf{X})]^{-1}), \quad (5.2)$$

where **H** stands for household characteristics, and $\mathbf{Z}_i \mathbf{Z}_j$ represents the interaction effect of productive inputs. For the estimation of this function, the study used the nonlinear least-squares procedure. Weather and soil characteristics can also influence yield.

The damage-control framework can account for the yield effect and also for the pesticide-reduction effect. The yield effect can take different forms that can be grouped into two broad categories. In the first category, a yield effect can be either a damage-control effect or the efficiency of the technology controlling the constraint. In the second category, a yield effect can be either the genotypic advantage of the GM variety or a pure yield effect. Qaim and Zilberman (2003) used the damage-control framework to evaluate the impact of GM cotton varieties in India and concluded that in countries where pest damage is significant and pesticides are not effectively used, the adoption of GM varieties would increase yield mainly by controlling damage but would have less impact on pesticide use. In countries with high pesticide use, the damage-control effect would be small, but the technology would help lower pesticide use and thus reduce health costs. Because the use of complementary inputs is low in Uganda, we expect to have a high damage-control effect and no pesticide effect.

Partial Budgets

To develop partial budgets, we followed the comprehensive guide published by the International Center for Maize and Wheat Improvement (CIMMYT 1988). As explained in the guide, a partial budget is a method used to organize and present benefits and costs of alternative treatments.[1] Reported use by farmers of such inputs as land, labor, insecticides, and herbicides is converted to values per hectare. Cottonseed is distributed free of charge and thus has zero cost for producers. We used the opportunity costs of land, equivalent to the average rent in the district, to account for land costs. Total family labor

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[1] It is typical to include total benefits but the costs only of inputs that vary with treatments. Because we are comparing not only alternative treatments but also production systems, we include in the partial budgets not only the costs of inputs that vary with the treatments but also the costs of inputs that vary with the production system.

costs are estimated using average wages paid to hired labor. As stated by Horna et al. (2008), this assumption is reasonable, because labor markets in selected districts are active and cotton is a commercial crop. Unfortunately, family labor was reported in the survey only as the total number of hours invested in cotton production during the production season and was not disaggregated by activity. Detailed information on hired labor and benefit-cost ratios are reported for both scenarios, with and without the inclusion of family labor. Male and female labor days are assigned equal costs, as there is no evidence available to justify valuing them differently.

To develop partial budgets for GM scenarios, yield losses due to targeted constraints are derived from the elicited yields, following the same steps as in Horna et al. (2008):

$$E(Y_{\text{loss}}) = \frac{\left[E(Y_{c=0}) - E(Y_{i,c=1})\right]}{E(Y_{c=0})}, \tag{5.3}$$

where $E(Y_{\text{loss}})$ is the expected yield loss ratio, $E(Y_{c=0})$ is the expected yield without the constraint, $E(Y_{c=1})$ is the expected yield with the constraint, and i indicates use of insecticide (1 if farmers use insecticide and 0 otherwise). Given expected yield losses, expected damage control with insecticide Y_{abat} is estimated as

$$E(Y_{\text{abat}}) = 1 - E(Y_{\text{loss}}). \tag{5.4}$$

This estimation is a fair approximation of damage control. Actual damage and damage control are variables that are difficult to estimate, whether from field experiments or data obtained from farmers. In the first case, control conditions can hardly replicate farmers' plot conditions. In the latter case, yield losses reported tend to be upward biased, because it is difficult for farmers to isolate the effect of damage from a specific constraint.

Stochastic Simulations

We ran four simulations to account for different production possibilities for farmers. The first simulation depicts an organic production system in which the premium price is replaced by a triangular distribution, where the low premium is 0 percent (when farmers do not get the premium), the mode is 12.5 percent (in cases where the premium is paid only on part of the harvest), and the high premium is 25 percent. This last value is the premium paid to organic farmers (as reported by the National Organic Agricultural Movement of Uganda). The mode value is half of this high premium. These values are used as a conservative approximation, as our records show no difference between the price paid to organic producers and that paid to conventional producers. A factor that may explain this observation is that farmers reported net income received from the ginnery, which may have already discounted transaction costs (transportation or ginnery fees) to a greater degree for organic producers. Moreover, in their evaluation of the organic sector, Ogwang, Sekamatte, and Tindyebwa (2005) reported that organic producers were receiving on average a 13 percent price premium. The second simulation is a hypothetical case in which it is possible to use Bt cottonseed in an organic system. The third and fourth simulations illustrate the case of the adoption of Bt cotton and herbicide-tolerant (HT) cotton, respectively.

From the experience of adopting countries, it is expected that GM seed's price will be higher than current seed prices, although the absolute value of this price varies widely according to the technology provider and its market power. Cost savings associated with the use of GM seed are measured by the reduction in insecticide applications, related labor costs (if any), or both. Assumptions used in the partial budget simulations are summarized in Table 5.2. To account for risk and uncertainty in agricultural production, some parameters were replaced by distributions. The distributions used in the study were based either on a literature review (in the cases of technology fees, the damage-control effect [technology efficiency] and reductions in pesticide and spraying costs) or on primary data collected from farmers (in the cases of yield variability within and across households, yield loss due to constraints, price fluctuations, pesticide use, and spraying).

We used the @Risk software (Palisade Corporation 2012) to generate the distributions. For variables with actual information available (such as season yield, use of inputs, and costs), @Risk estimated candidate distributions and selected the one that best fit the information collected in the survey. For variables that represented farmers' judgments or perceptions—specifically of yield behavior over time—@Risk selected the triangular distribution that best fit the information elicited from farmers at three moments: (1) without the constraint, (2) with the constraint but without insecticide use, and (3) with the constraint and insecticide use. In @Risk, the study drew from the sample distributions of each yield parameter (minimum, maximum, and mode) to identify yield variability both in and across observations. Note that in @Risk's parlance, there are two kinds of variables (distributions): input variables that are predetermined and output variables that are estimated based on input variables.

Best-fit distributions were used for variables that were easy to obtain from farmers: (1) output price, (2) pesticide cost, and (3) spraying cost. In contrast,

TABLE 5.2 Variables and distributions used for partial budget simulations

Variable	Distribution	Assumptions and source
Yield (kilograms per hectare)	@Risk best-fit distribution	Based on information collected from farmers
Yield losses due to bollworm and lack of weeding (percent)	@Risk best-fit distribution	Based on information collected from farmers
Technology efficiency (percent)	Triangular distribution	Values: minimum = 0, mode = 50, and maximum = 100, based on literature for both Bt cotton and HT cotton (Pray et al. 2002; Qaim 2003; Traxler and Godoy-Ávila 2004)
Output price (US$ per kilogram)	@Risk best-fit distribution	Based on information collected from farmers
Seed cost (US$ per kilogram)	Not a distribution	Seed is distributed free of charge; the value assumed was US$0.205 per kilogram; on average, farmers can use 10 kilograms per hectare of seed for planting cotton
Premium price (percent)	Triangular distribution	Values: minimum = 0, mode = 12.5, and maximum = 25; these values represent the increase, for organic producers, over the official price
Technology fee (percent)	Triangular distribution	***Scenario 1:*** Values: minimum = 0, mode = 50, and maximum = 100; these values represent the increase over the seed price ***Scenario 2:*** Range of values found in the literature (Falck-Zepeda, Traxler, and Nelson 2000; Huang et al. 2003, 2004; Bennett et al. 2004), including US$15 per hectare for India, US$32 per hectare for South Africa and China, and US$56 per hectare for the United States
Pesticide cost (US$ per hectare)	@Risk best-fit distribution	Based on information collected from farmers
Reduction rate in pesticide used to control lepidoptera (percent)	Triangular distribution	Values: minimum = 0, mode = 50, and maximum = 100
Herbicide use (US$ per hectare)	@Risk best-fit distribution	Based on information collected from farmers
Increase in herbicide use (percent)	Triangular distribution	Values: minimum = 0, mode = 50, and maximum = 100; these values represent the increase over the average among current herbicide users
Labor for pesticide application (US$ per hectare)	@Risk best-fit distribution	Based on information collected from farmers
Reduction rate in labor used for pesticide application (percent)	Triangular distribution	Values: minimum = 0, mode = 25, and maximum = 50; these values represent the reduction in labor as a result of the reduction in total pesticide applied
Labor for herbicide application (US$ per hectare)	@Risk best-fit distribution	Based on information collected from farmers
Increase in rate of labor used for herbicide application (percent)	Triangular distribution	Values: minimum = 0, mode = 25, and maximum = 50; these values represent the increase over the average, among current herbicide users, of labor used to apply herbicides

Source: Authors.

Note: Bt = insect resistant; HT = herbicide tolerant.

triangular distributions were used to model variables that measure (i) technology efficiency (trait expression), (ii) technology fees, (iii) rates of reduction in pesticide use, (iv) rates of reduction in spraying costs in the case of Bt cotton, and (v) increased rates of herbicide use in the case of HT cotton. An explanation of minimum, mode, and maximum values adopted for all these variables is given in Table 5.2.

The effect on labor of the use of GM varieties depends on the type of material used. The use of Bt cotton varieties can lead to a reduction in the labor employed for chemical applications. However, if the expected yield increase from Bt cotton use is high, then harvesting will require more labor. But the study assumed that yield increases would not necessarily lead to higher labor use, because yield levels are currently rather low in Uganda. The use of HT cotton implies a reduction in the labor used for manual weeding but an increase in the labor used for herbicide application. Not many farmers currently make use of herbicides in Uganda. Of those who do, few apply glyphosate.

The results of the real and simulated partial budgets were compared using first-degree stochastic dominance. Stochastic dominance is a nonparametric approach used to rank competing alternatives, strategies, or policies based on their risk characteristics (see Appendix 6). This approach ranks alternatives into dominating and dominated sets based on stochastic efficiency rules. Stochastic efficiency rules are pairwise comparisons of the estimated cumulative distribution functions derived from observed or simulated data (or both) describing an outcome or action. In most cases, these distribution functions tend to intersect. Thus, additional and more restrictive assumptions are needed to allow the ranking.

Technology-Fee Scenarios

The technology fee is a sensitive issue because GM-seed price affects adoption. This study developed two contrasting technology-fee scenarios to evaluate its effect on farmers' welfare.

In the first scenario, the technology fee is expressed as a percentage increase of the assumed seed price.[2] The study used a triangular distribution

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[2] Currently farmers do not pay for the seed, as it is assumed that it is distributed free of charge, so there is no information about the price of the cottonseed. The study therefore uses the nominal farmgate price charged by farmers for their seed cotton (Tschirley, Poulton, and Labaste 2009). As with other crops, the price of the seed is expected to be higher than the farmgate price of the commodity; this is, however, the best approximation of the seed's real value. Also, note that ginneries select the best cottonseed after delinting and then give it back to the Cotton Development Organisation.

in which the low percentage increase over the value of the conventional seed was 0 percent, the mode was 50 percent, and the high was 100 percent. Because the assumed price of the conventional seed was zero, the market price for the GM seed, including the technology fee, ended up being still much lower than real GM seed prices charged in developing countries that have already adopted the technology. However, this scenario was useful in understanding what the benefits would be to farmers with a technology fee subsidized by the public sector.

In the second scenario, the technology fee is expressed as a triangular distribution in which the low ($15 per hectare),[3] mode ($32 per hectare), and high ($56 per hectare) values are based on the final values charged for GM cottonseed in other countries. This scenario represents the extreme case in which the technology fee is fully paid by farmers.

Characterizing Cotton Producers

Farm and household characteristics have an effect on the adoption of GM cotton. Analysis of GM cotton adoption highlights the importance of farm size, labor availability, access to credit and production inputs, and risk preferences. These and other key variables have a major influence on the adoption of agricultural technologies, especially high-yielding crop varieties (Feder, Just, and Zilberman 1985). The crucial farm household characteristics and production variables are summarized by district in Table 5.3.

The statistics in this table describe well the situation of cotton production across districts in Uganda: small plots, low input use, and low productivity.[4] As mentioned earlier, Lira and Kasese are important cotton-producing districts. Lira is the district where organic production has expanded faster. Kasese is among the most important cottonseed-producing districts, being the largest producer in 2006. The higher concentration of ginneries in this district is probably explained by the favorable conditions for cotton production. Although our sampling strategy was strongly linked to the selection of sites for the implementation of the confined field trials and therefore might suffer from bias, the information in Table 5.3 is still similar to the conditions in other cotton-producing districts in Uganda. Note that, although our sample's mean seed cotton yield of 953.48 kilograms per hectare is higher than the

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[3] All dollars are U.S. dollars in the chapter.

[4] The mean size of cotton plots in Lira (0.44 hectares) is comparable to the average plot size of 0.41 hectares reported by UBOS (2007) (which used information from UHNS for 2005/06).

TABLE 5.3 Descriptive statistics for farm households by district

	Total sample (N = 151)		Lira (N = 35)		Kasese (N = 116)			
Variable	Mean	Standard error	Mean	Standard error	Mean	Standard error	*t*-test	*P*-value
Gender of household head (female = 1)	0.09	0.02	0.03	0.03	0.11	0.03		
Control of plot (female = 1)	0.46	0.08	0.29	0.13	0.51	0.09		
Age of household head (years)	44.04	1.14	42.63	2.85	44.47	1.22		
Education level of household head (years)	2.90	0.15	3.03	0.30	2.86	0.18		
Household size (number)	7.75	0.31	7.40	0.52	7.86	0.38		
Number of men older than 16	1.86	0.11	2.23	0.22	1.75	0.12		
Number of women older than 16	1.74	0.10	1.71	0.17	1.75	0.12		
Number of people 16 or younger	4.15	0.23	3.46	0.33	4.36	0.28		
Experience with cotton (years)	14.68	1.04	16.86	2.36	14.02	1.15		
Yield loss from bollworm (percent)	0.74	0.35	0.59	0.38	0.78	0.33	2.8926	0.004
Land value (US$)	1,192.90	2,330.54	1,167.10	1,634.88	1,200.68	2,508.77		
Total area (hectares)	1.42	2.42	1.34	2.51	1.45	2.40		
Cotton area (hectares)	0.68	0.55	0.44	0.24	0.75	0.59	3.0129	0.003
Seed cotton price (US$ per kilogram)	0.39	0.06	0.39	0.08	0.39	0.05		
Seed cotton yield (kilograms per hectare)	953.48	719.66	675.53	548.62	1037.34	745.61	2.6592	0.009
Output value (US$ per hectare)	630.37	805.60	288.97	253.32	733.37	883.95	2.9320	0.004
Dummy for organic producer	0.34	0.48	0.34	0.48	—	—		
Dummy for use of herbicides	0.09	0.29	—	—	0.09	0.29		
Herbicide use (US$ per hectare)	1.38	5.70	—	—	1.38	5.70		
Dummy for use of fertilizer	0.09	0.29	0.03	0.17	0.11	0.32		
Fertilizer use (US$ per hectare)	1.01	7.06	0.04	0.23	1.30	8.04		
Dummy for use of pesticides	0.97	0.16	0.89	0.32	1.00	0.00	3.8431	0.000
Pesticide use (US$ per hectare)	21.52	20.89	9.42	26.23	25.16	17.55	4.1079	0.000
Labor for weeding (US$ per hectare)	69.41	70.89	66.79	86.11	70.20	66.03		
Labor for herbicide application (US$ per hectare)	0.18	0.83	—	—	0.18	0.83		
Labor for pesticide application (US$ per hectare)	6.94	10.86	4.31	7.91	7.73	11.51		
Total hired labor (US$ per hectare)	147.52	127.98	164.62	179.92	142.35	108.07		

Source: Authors' survey data.

Notes: *t*-test and *P*-value included only when significant. — = not applicable.

national average of about 400 kilograms per hectare reported by FAOSTAT for Uganda in 2007, productivity values are quite low.

Although household characteristics in Lira and Kasese are similar, some production variables are significantly different. Household size and composition, and the household head's age and level of education, are relatively similar across sites. Nor is there significant variation concerning land value, labor use, and years of experience in cotton cultivation. On average, farmers interviewed have more than 14 years of experience working with cotton. The size of cotton areas tends to be larger in Kasese. Similarly, seed cotton yield and output value generated from cotton production are also higher in Kasese. These results correspond to reports by local institutes. In contrast, it seems that the susceptibility to cotton bollworm is higher in Kasese (in Western Region) than in Lira (in Northern Region). According to cotton experts, this behavior can be extended to the regions, implying that Bt cotton could have greater success in Western than in Northern Region. Average productivity is also higher in Kasese. Interestingly, organic insecticides are used by the majority of producers both in Kasese and Lira. However, the average investment in pesticides is significantly different between the districts, being higher for Kasese.

If the Ugandan government decides to approve the introduction and commercialization of GM cotton varieties, a geographic segregation of areas planted to GM and non-GM cotton could be an alternative to take into consideration. Northern Region and other regions where organic cotton production is important could remain as GM-free areas.

To get some insights about farmers' behavior with respect to GM seed technology, we artificially classified producers as "low-input" and "high-input" users. Obviously this classification is also a proxy for income level. Because basically all conventional producers applied insecticides but very few applied mineral fertilizers, we used chemical fertilizer application as a criterion to classify producers. Therefore, the category "high-input user" refers to farmers that use chemical fertilizers and more than the average amount of pesticides. From a total of 151 observations, only 27 qualified as high-input users. All organic producers were categorized as low-input users. Table 5.4 presents the descriptive statistics of key variables by type of producer. We noticed that there were significant differences between low-input and high-input users in level of experience and total labor used but not in total area. In other words, high-input producers in our sample were using more inputs (chemical fertilizers, insecticides, and labor), independently of farm size.

Note also that the price of seed cotton obtained by high-input users was statistically higher than the one received by low-input users. Clearly, better quality produce fetched a higher price and allowed a higher investment in inputs. Accessibility is often the main reason for high-input use: farmers who are closer to markets tend to use more inputs when available. The total magnitude of investment in inputs was probably the result of either shorter distances to markets or other points of sale or better access to credit sources. Either way, an intervention is needed to guarantee farmer accessibility to good quality inputs and thus increase the use of productive inputs not only among low-input users but also among all types of producers. Low-input users could face similar constraints in reaching GM cotton technology as for any other productive inputs. Characteristically, credit can be particularly critical for cotton production because of the high use and cost of pesticides and the high labor demands throughout the planting season.

Gender of the household head and asset control can affect adoption and management of GM varieties (Table 5.5). Female-headed households probably have different priorities in the technology adoption process than

TABLE 5.4 Descriptive statistics for farm households by type of producer

	Low-input users (*N* = 124)		High-input users (*N* = 27)		
Variable	Statistic	Standard error	Statistic	Standard error	*F*
Gender of household head (female = 1)	0.08	0.27	0.15	0.36	
Age of household head (years)	43.49	13.39	46.22	17.33	
Education level of household head (years)	2.77	1.86	3.44	1.89	
Land value (US$ per hectare)	2,568.01	5,708.80	3,929.03	4,523.43	
Total area (hectares)	1.30	2.31	1.90	2.80	
Cotton area (hectares)	0.69	0.58	0.64	0.30	
Experience with cotton (years)	13.73	12.30	18.81	14.30	3.6*
Yield loss from bollworm (percent)	0.74	0.35	0.67	0.36	
Seed cotton price (US$ per kilogram)	0.38	0.04	0.41	0.03	31.3***
Output value (US$ per hectare)	583.81	808.54	713.27	580.04	
Seed cotton yield (kg/ha)	918.46	715.10	1,132.78	705.57	
Labor used for weeding (US$ per hectare)	60.57	65.07	95.70	75.28	3.6**
Total labor used (US$ per hectare)	132.45	112.67	188.25	157.35	3.0**

Source: Authors' survey data.

Notes: * indicates significance at the 10 percent level, ** indicates significance at the 5 percent level, and *** indicates significance at the 1 percent level.

do male-headed households. Female-headed households are usually not common and could easily be underrepresented in a sample. The household head, however, does not necessarily manage all the plots. In our case, although the percentage of female household heads was low (3 percent in Lira and 11 percent in Kasese), the share of plots managed by women was 51 percent in Kasese and 29 percent in Lira. Interestingly, when testing for mean differences between plots managed by men or women, none of the variables included in Table 5.5, except for gender and age of the household head, were significantly different.

In contrast to our finding, Baffes (2009) reports a large productivity gap for the southeastern cotton-producing region, with male growers often achieving yields three or four times higher than that of their female counterparts. We speculate that these differences are due more to the approach used to evaluate gender issues than to geographic differences. In other words,

TABLE 5.5 Descriptive statistics for farm households by gender

	Male-controlled plot (*N* = 112)		Female-controlled plot (*N* = 24)		
Variable	Statistic	Standard error	Statistic	Standard error	*F*
Gender of household head (female = 1)	0.03	0.02	0.46	0.10	55.56***
Age of household head (years)	42.88	1.36	50.13	2.70	5.16**
Education level of household head (years)	2.93	0.18	2.42	0.34	
Land value (US$ per hectare)	2,660.02	471.26	2,782.70	514.64	
Total area (hectares)	1.38	0.21	1.35	0.20	
Cotton area (hectares)	1.62	0.11	1.35	0.15	
Experience with cotton (years)	14.52	1.24	15.04	2.37	
Yield loss from bollworm (percent)	0.71	0.03	0.76	0.06	
Seed cotton price (US$ per kilogram)	0.38	0.00	0.38	0.00	
Output value (US$ per hectare)	535.44	51.97	554.97	58.71	
Seed cotton yield (kilograms per hectare)	932.60	63.28	949.38	71.54	
Labor used for weeding (US$ per hectare)	66.87	6.00	66.50	6.89	
Total labor used (US$ per hectare)	140.54	10.91	140.85	12.61	

Source: Authors' survey data.

Notes: ** indicates significance at the 5 percent level, and *** indicates significance at the 1 percent level.

although female-headed households are getting lower yields than male-headed households (Baffes 2009), these differences might be unobservable when the unit of comparison is not the head of household but the person managing the plot. Both comparisons have important implications for GM adoption and impact. Comparing household heads by analyzing the impact of GM technologies on disadvantaged female-headed households is essential to discussing poverty reduction and welfare effects (Meinzen-Dick et al. 2010). Comparing plot managers by assessing plot management strategies will help us understand differences in the decisionmaking process with respect to adoption of GM technologies.

Yield Determinants

According to the primary information collected, the main inputs used in cotton production in the selected sites are seeds, chemical and organic fertilizers, chemical and organic pesticides, herbicides, and labor. As discussed earlier, seed is distributed by ginneries, and farmers do not directly pay for it. Seed quality could be a constraint, depending on the previous year's harvest. Use of organic fertilizers and organic pesticides occurs mainly in Lira, where organic production is concentrated. Use of chemical fertilizers and pesticides is more common in Kasese. The use of these inputs is rather limited, however. Our survey shows that in 2007, only six farmers used chemical fertilizers and only three of them used an organic fertilizer. Table 5.6 shows the results of the production function regression using the damage-control specification. This table shows that fertilizer does not have a significant effect on yield performance (low *t*-values). Cotton is a labor-intensive crop, especially when produced organically, and labor, both family and hired, contributes significantly to yield performance.

In the damage-control part of the production function (Table 5.6), neither pesticides nor herbicides seem to be controlling damage caused by pest and weeds to any significant degree, as shown by the lack of statistical significance of these variables. This demonstrates the current underutilization of these inputs. Thus, investment in fertilizers, good quality seed, and other inputs is crucial to improving the poor cotton performance in Uganda. Although the introduction of GM seed could help control bollworm and weeds and reduce the amount of labor used for weeding, cotton would hardly achieve its full yield potential if the applications of fertilizer and other productive inputs remain at their current levels.

TABLE 5.6 Production function using a damage-control specification

Explanatory variable	Coefficient	Standard error	*t*-value
Production function			
Constant	198.56	37.72	5.26***
District (dummy, Kasese = 1)	219.46	83.22	2.64***
Altitude (miles above sea level)	–0.25	0.09	–2.76***
Organic producer (dummy)	242.5	171.51	1.41
Land rent (US$ per hectare)	–0.61	1.37	–0.45
Square of land rent	0	0	0.73
Family labor (US$ per hectare)	0.38	0.16	2.41**
Square of family labor	0	0	–2.07**
Fertilizer (US$ per hectare)	11.61	9.56	1.21
Square of fertilizer	0	0	–0.30
Hired labor for harvesting (US$ per hectare)	2.19	1.66	1.32
Square of hired labor for harvesting	0	0	–0.16
Hired labor for other activities (US$ per hectare)	4.72	0.83	5.68***
Square of hired labor for other activities	0	0	–4.32***
Damage control			
Constant	10.54	10.57	1.00
Pesticide and labor used to apply pesticides (US$ per hectare)	0.57	0.57	1.01
Herbicide and labor used in weeding (US$ per hectare)	0.07	0.07	0.95

Source: Authors' survey data.

Notes: ** indicates significance at the 5 percent level, and *** indicates significance at the 1 percent level. $R^2 = 0.45$; adjusted $R^2 = 0.38$.

Production Costs

The production costs for both conventional and organic production systems are presented in Table 5.7. Even though the organic system has a slightly higher benefit-cost ratio, both systems have low profitability, especially after including family labor. Cotton production is generally a risky business: note that the downside risk (that is, the probability of having a negative profit) is high for both systems.

Conventional System

Cotton is a low-profitability activity in Uganda regardless of the production system (Table 5.7). Although the reported productivity of seed cotton for the sample (about 900 kilograms per hectare) is above the reported national average (about 400 kilograms per hectare), the benefit-cost ratios estimated are

TABLE 5.7 Cotton profitability, 2007/08 season

Income or cost component	Conventional (*N* = 139)	Share (percent)	Organic (*N* = 12)	Share (percent)
Yield (kilograms per hectare)	962.05	—	863.46	—
Price reported by farmers (US$ per kilogram)	0.38	—	0.38	—
Total income (US$ per hectare)	366.76	—	328.21	—
Land rent (US$ per hectare)	74.99	22	72.25	26
Chemical fertilizer (US$ per hectare)	24.56	7	0.00	—
Organic fertilizer (US$ per hectare)	20.23	6	22.01	8
Herbicide use (US$ per hectare)	17.16	5	0.00	—
Pesticide to control lepidoptera (US$ per hectare)	23.61	7	—	—
Pesticide to control other insects (US$ per hectare)	17.44	5	—	—
Organic pesticide (US$ per hectare)	—	—	4.82	2
Hired labor to apply pesticides (US$ per hectare)	7.24	2	3.37	1
Hired labor to apply herbicides (US$ per hectare)	5.42	2	0.00	—
Hired labor for weeding (US$ per hectare)	70.91	20	61.20	22
Hired labor for harvesting (US$ per hectare)	28.92	8	28.90	10
Hired labor for other activities (US$ per hectare)	57.49	17	89.09	32
Family labor (US$)	423.98	—	1,652.39	—
Total costs (US$ per hectare)	347.98	—	281.66	—
Margin (US$ per hectare)	18.78	—	46.56	—
Downside risk (percent)	38.60	—	52.00	—
Benefit-cost ratio	1.05	—	1.17	—

Source: Authors' survey data.

Notes: Values presented are the mean values of field observations. An average wage rate of US$2.90 per day is used to estimate the opportunity costs of family labor. When family labor is added to the estimations in the table, the benefit-cost ratio decreases significantly, falling to 0.48 for conventional producers and to 0.17 for organic producers. — = not applicable.

still low.[5] Conventional producers do get a higher benefit-cost ratio, but the returns are very low when family labor is taken into account. Moreover, the opportunity costs of family labor could be underestimated, as family labor estimates are drawn from farmers' recollections and their subjective valuation (use) of their own labor.

Under conventional production, most farmers use some type of chemical control to deal with insect pests. Relatively few use fertilizers, and almost none use herbicides. This last input could contribute significantly to improving crop

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[5] According to FAO (2010), average productivity for seed cotton has been about 417 kilograms per hectare for the past 5 years, and for the past 10 years it has been about 347 kilograms per hectare.

profitability. Cotton is a labor-intensive crop; labor represents about 50 percent of total production costs—more than 50 percent in the case of organic producers. Most labor is used for manual weeding. Weed infestation is therefore another severe constraint on cotton production. In the study sample, weeding represents about 20 percent of the total labor costs for both types of producers. Other institutions working in cotton in the area report similar patterns (Agricultural Productivity Enhancement Program, personal communication, 2008).[6]

In short, cotton is a labor-consuming activity, and weeding is particularly labor demanding. So, freeing labor from weeding could allow family members to be available for other economic activities. In contrast, freeing labor through the use of HT seed could have a negative impact on employment and welfare in the community if there are no productive off-farm labor opportunities.

Farmers in Kasese and Lira seem to have serious problems with bollworm. On average, this pest can damage up to 70 percent of expected output. Although these estimations are based on farmers' perceptions and may have an upward bias, they are a good reference point for understanding the severity of bollworm infestation in these regions. In addition to bollworm, there are other common biotic stresses, such as aphids, *Lygus* spp. (sucking-type insects), and cotton strainers. The severity of these biotic constraints, combined with high price variability and poor access to inputs, has transformed cotton production into a highly risky activity in Uganda. The estimated downside risk (nearly 40 percent) for surveyed conventional farmers illustrates the magnitude of the problem.

Organic System

One of the purposes of the implementation of household surveys in Lira was to cover organic producers and collect information to generate a representative partial budget for an average organic cotton producer. Nevertheless, only 12 of the 35 self-identified organic producers qualified as actual standard-complying organic producers. The remaining 23 admitted using some chemicals to control heavy pest infestations. In fact, the number of organic farmers appears to change from year to year, as farmers seem to switch from conventional to organic with relative ease. According to the company Dunavant, in the 2006/07 season, 11,691 organic farmers were registered and contracted for a total production of 6,600 bales (about 185 kilograms per bale),

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[6] Survey results do not support the general notion that women manage cotton agronomic practices (weeding in particular).

which accounted for almost one-third of Dunavant production. During the 2008/09 season, there were serious problems with the production of organic cotton, because army bollworms infested the crop.

Even though it is not possible to make statistical inferences based on a small number of observations, the analysis of household survey information can provide some useful insights. It is well known, for instance, that the profitability of organic cotton is significantly low (Ogwang, Sekamatte, and Tindyebwa 2005). For the sampled farmers, the marginal benefits are less than 17 percent of total costs. In addition, the downside risk—the risk of not being able to cover at least the production costs—is higher than 50 percent (see Table 5.7).

As with conventional production, organic cotton faces several biotic and abiotic constraints. Surveyed farmers report that the damage caused by bollworm is greater than 50 percent (see Table 5.3). Similar to conventional cotton, the main cost in organic cotton production is labor (65 percent). Organic production generally requires a significant amount of labor for manual activities, including insect and weed control. Our study does not have information about specific control practices implemented.

Simulation Results

The profitability of cotton production is low for all the simulations and scenarios accounting for the two different technology fees. Also, none of the simulations show first-degree stochastic dominance over the others, which confirms that none has an outcome that is clearly better on average than the others. Note also that the downside risk of each alternative is high, but it is particularly high for the scenario with a higher technology fee.

Bt and HT cotton are good alternatives that may partly reduce the risk in cotton production, especially when the technology fee is low (Table 5.8, technology fee 1). However, the reduction of downside risk depends on the effectiveness of the GM technology in controlling the constraint (expression of the trait). Experts report that yield losses stemming from bollworm could be as high as 80 percent, which is in agreement with what farmers have reported (on average, about 76 percent). Given these high values attached to farmers' perceptions about yield losses from bollworm attack and weed infestation, it is not surprising that the margins are higher for both the Bt cotton and HT cotton scenarios than they are for the organic cotton scenario with technology fee 1. But perceptions are usually upward biased, given that it is rather difficult for farmers to isolate the net effect of one constraint from all the other constraints they face.

The results of the simulation show that the marginal benefits and the benefit-cost ratio are higher when GM seed is used. The marginal benefits of using GM seed are directly related to the level of incidence of the productivity constraint and the actual damage caused by the biotic constraint. This is particularly interesting, because the average technology efficacy is 50 percent, meaning that the GM seed is able to control at least 50 percent of the yield losses caused by bollworm and by weeds. To generate the distribution for technology efficiency, we allowed the efficacy rate to vary from no efficiency at all (0 percent) to full control of the constraint (100 percent efficiency). The literature shows that this is a sensible assumption (Qaim and Zilberman 2003).

For the HT cotton simulation, the assumptions are based on expectations. This simulation records the highest benefit-cost ratio and the highest marginal rate of return over low-input or organic production systems. Unfortunately, it also produces the least solid results because of lack of technical information (for example, the number of weeding sessions avoided with one application of the herbicide Roundup® [Monsanto, Marysville, OH]), yield loss due to weeds, and the comparatively low number of respondents. Unlike Bt cotton, which has been documented relatively well, there is only scattered technical information about the performance of HT cotton in farmers' fields.

Organic cotton is relatively attractive for farmers who already use few inputs and no chemical pesticides and can gain from receiving a price premium. According to public sources, this premium can be as high as 20 percent more than the usual price per bale of seed cotton (ACE 2006), although prices reported by farmers in Lira do not seem to be considerably higher than those received by conventional producers. This difference could be explained by transportation and ginnery fees charged to producers, because farmers report total income from selling their cotton production rather than price per bale of seed cotton. Table 5.8, fifth column, illustrates a simulation of organic production with an effective price premium that results in better cotton profitability (benefit-cost ratio) than the one reported for organic producers in Table 5.7. Nevertheless, given the high downside risk of organic cotton and its low profitability, it is a far less appealing option for farmers than producing GM cotton with a low technology fee. However, when the technology fee of GM cotton is at international levels (technology fee 2 in Table 5.8), the profitability of organic cotton is higher than in any other simulation, including the simulation where Bt cotton seed is used in an organic system. The latter actually recorded the highest downside risk (55.6 percent), which is explained partly by the high yield variability of organic cotton and partly by the limited number of observations for organic producers.

TABLE 5.8 Partial budget simulations

Cost component	Bt cotton	HT cotton	Organic + premium price	Organic + Bt cotton
Yield (kilograms per hectare)	1,325.40	1,342.60	863.50	1,101.34
Yield loss from bollworm (percent)	76.00	—	55.00	55.00
Yield loss from weeds (percent)	—	79.00	—	—
Technology efficacy (percent)	50.00	50.00	—	50.00
Price reported by farmers (US$ per kilogram)	0.38	0.38	0.43	0.43
Premium price (US$ per kilogram)	—	—	12.50	12.50
Total income (US$ per hectare)	505.27	511.83	369.24	470.97
Seed cost[a] (US$ per hectare)				
Technology fee 1	1.58	1.58	0.00	1.58
Technology fee 2	128.00	128.00	0.00	128.00
Land rent (US$ per hectare)	74.99	74.99	72.25	72.25
Chemical fertilizer (US$ per hectare)	24.56	24.56	0.00	0.00
Organic fertilizer (US$ per hectare)	20.23	20.23	22.01	22.01
Herbicide use (US$ per hectare)	17.16	25.74	0.00	0.00
Rate of herbicide use increase (percent)	—	50.00	—	—
Pesticide to control lepidoptera (US$ per hectare)	11.81	23.61	—	—
Rate of pesticide use reduction (percent)	50.00	—	—	—
Pesticide to control other pests (US$ per hectare)	17.44	17.44	—	—
Chemical pesticide (US$ per hectare)	—	—	0.00	0.00
Organic pesticide (US$ per hectare)	—	—	4.82	4.82
Labor to apply pesticides (US$ per hectare)	5.43	7.24	3.37	2.53
Rate of labor cost reduction (percent)	25.00	—	—	25.00
Labor to apply herbicides (US$ per hectare)	5.42	8.13	0.00	0.00
Rate of increase in labor costs (percent)	—	50.00	—	—
Labor for weeding (US$ per hectare)	70.91	35.45	61.20	61.20
Rate of labor cost reduction (percent)	—	50.00	—	—
Labor for harvesting (US$ per hectare)	28.92	28.92	28.90	28.90
Labor for other activities (US$ per hectare)	57.49	57.49	89.09	89.09
Family labor (US$ per hectare)	423.98	423.98	1,652.39	826.19
Technology fee 1				
Total costs (US$ per hectare)	335.94	325.40	281.66	282.39
Margin (US$ per hectare)	169.33	186.44	87.58	188.57
Downside risk (percent)	26.80	21.60	48.40	40.80
B-C ratio	1.50	1.57	1.31	1.67
Technology fee 2				
Total costs (US$ per hectare)	462.36	451.82	Same as above	408.81
Margin (US$ per hectare)	42.91	60.02		62.15
Downside risk (percent)	43.90	38.70		55.60
B-C ratio	1.09	1.13		1.15

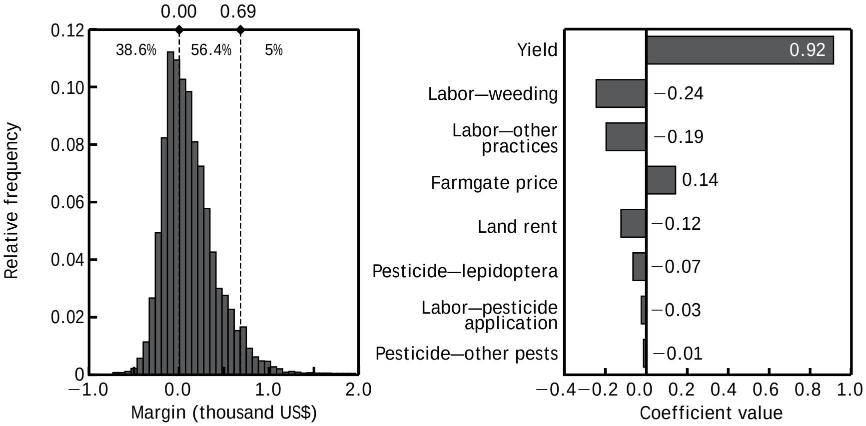
Source: Authors' survey data.

Notes: Numbers are rounded estimates. When family labor is added to the estimations using the average wage rate (US$2.90 per day), some changes occur. In the case of technology fee 1, the B-C ratio decreases to 0.66 for Bt cotton, 0.68 for HT cotton, 0.19 for organic production that can get at least half of the premium price offered, and 0.42 for a production that combines organic management with Bt cotton technology. In the case of technology fee 2, the B-C ratio decreases to 0.57 for Bt cotton, 0.58 for HT cotton, and 0.38 for production that combines organic management with Bt cotton technology. B-C ratio = benefit-cost ratio; Bt = insect resistant; HT = herbicide tolerant; — = not applicable.

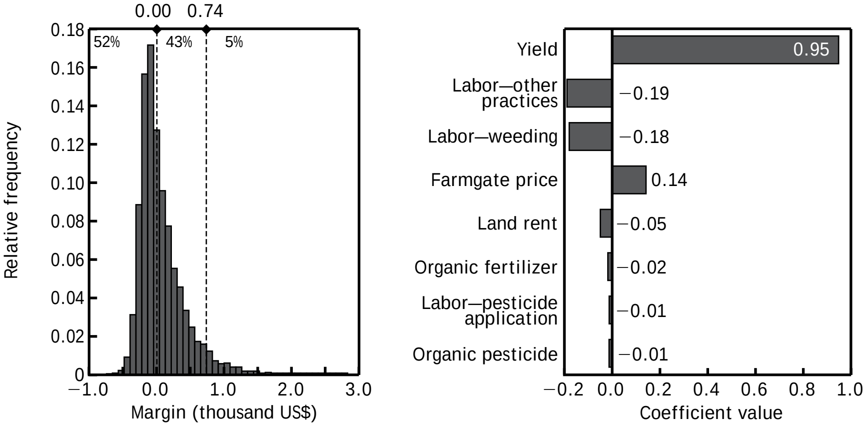
[a] Seed is assumed to be applied at the rate of 10 kilograms per hectare.

FIGURE 5.1 **Distribution and sensitivity of marginal benefits for cotton producers**

(a) Conventional production



(b) Organic production

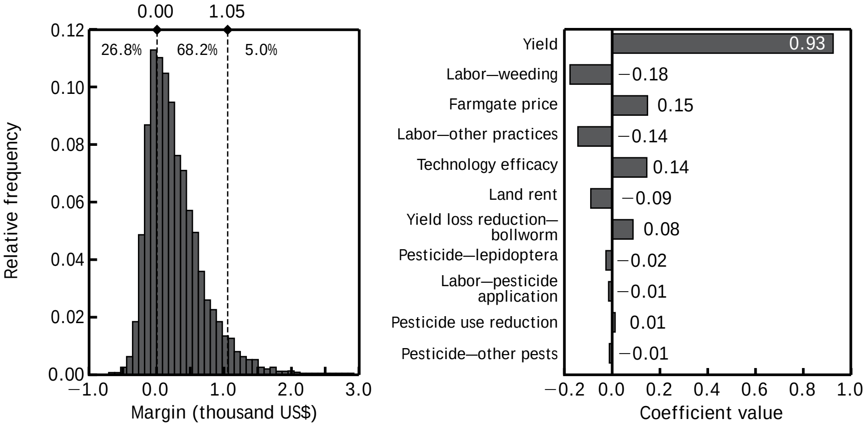


Source: Authors' survey data.

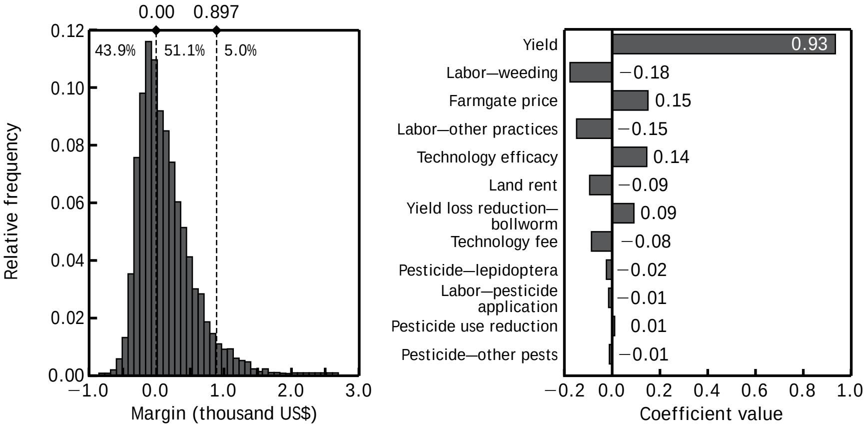
In terms of productivity, conventional producers are expected to perform better than organic producers, as shown in Table 5.8. Among probable production options, the rate of returns is higher for farmers who make use of chemical inputs and pay a low technology fee, even considering a premium price for organic cotton. However, in reality, organic producers do not seem to be getting a premium price for their product. If there is no premium price, then there are no marginal returns that will provide incentives to farmers to move from low-input production to organic production. If there is a premium

FIGURE 5.1 **(continued)**

(c) Bt cotton, technology fee 1



(d) Bt cotton, technology fee 2



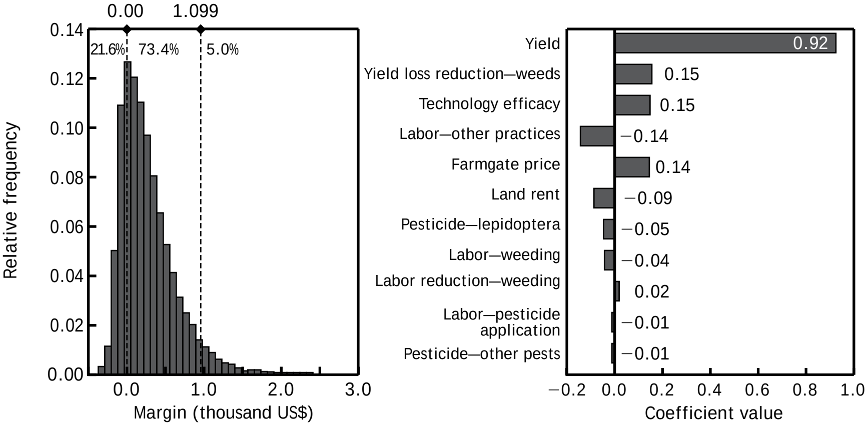
Source: Authors' survey data.

price and if the technology fee for GM seed is set at international standards and fully charged to farmers, then the marginal returns to organic production are the highest across all simulations.

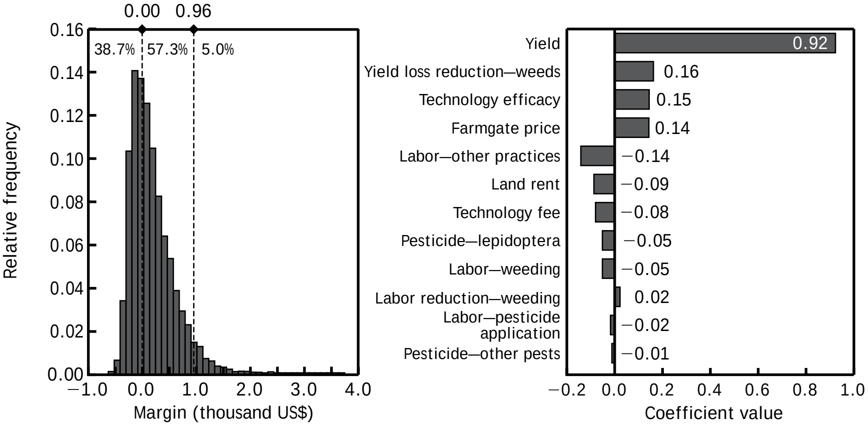
Figure 5.1 shows both histograms and tornado graphs for eight production alternatives. The histograms present the distribution of marginal benefits of real and simulated production alternatives: conventional, organic, conventional using Bt cottonseed, conventional using HT cottonseed, and organic using Bt cottonseed. See Appendix 7 to find the graphs for the

FIGURE 5.1 (continued)

(e) HT cotton, technology fee 1



(f) HT cotton, technology fee 2

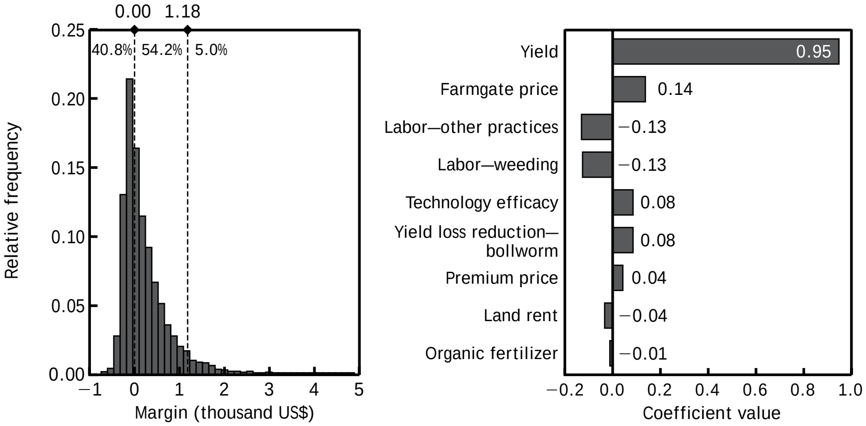


Source: Authors' survey data.

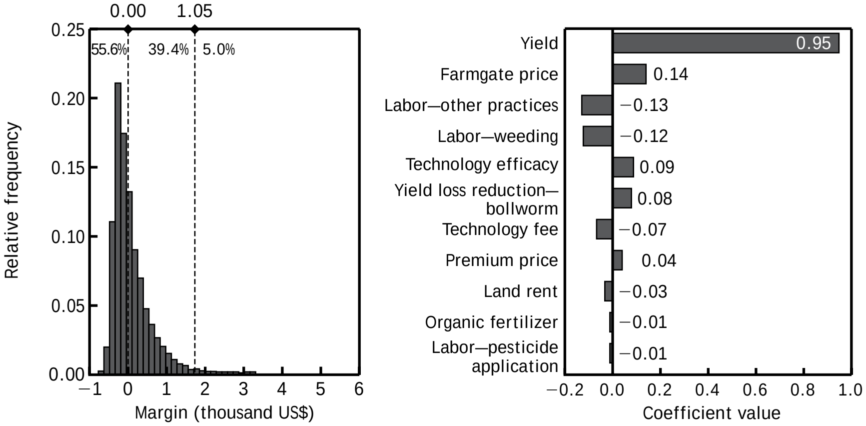
organic plus premium price scenario. The tornado graphs present the sensitivity of marginal benefits to the different input variables that use a probability distribution in the simulation. The @Risk software generates these tornado graphs by estimating a simple linear regression using marginal benefits (or any other output variable) as the dependent variable and all the input variables substituted with probability distributions as explanatory variables. The value of each coefficient can be interpreted as a measure of how much the output (marginal benefits) would change if the input variables

FIGURE 5.1 (continued)

(g) Organic + Bt cotton, technology fee 1



(h) Organic + Bt cotton, technology fee 2



Source: Authors' survey data.

(such as yield or technology fee) were changed by the equivalent of one standard deviation.

Note that a subsidized technology fee (technology fee 1) does not have a significant effect on marginal benefits. This situation changes when the technology fee is set at international levels (technology fee 2). Across all production alternatives, the variability in yield and the high labor costs are the main determinants of the margins generated. A technology that contributes to reducing yield variability would have a definitive impact on farmers' welfare.

Sensitivity Analysis

The adoption of an agricultural technology depends critically on the degree to which the technology is able to reduce risk and uncertainty in production.[7] Two of the greatest sources of uncertainty and risk in rainfed agriculture in Africa south of the Sahara are future rainfall patterns and output prices, which can have consequences involving income loss, missed opportunities for increasing income, or both (Kelly 2006). The sensitivity analysis presented here deals with risk but not with uncertainty: we use change in marginal benefits as a risk indicator. Reducing risks can change farmers' perceptions of a technology and increase the incentives to adopt it; thus, farmers can better capture the full potential of the technology.

The results of our simulations in Table 5.8 are subject to a number of assumptions that allowed us, as much as possible, to insert variability into the simulations. The assumptions are based either on expert information or on information from highly regarded publications. However, some aspects of the biology and agronomic performance of the crop are harder to simplify into general assumptions, because they involve complex relationships and interactions. Under ex ante conditions, where there is no technical information available, the situation is somewhat more complicated. Accounting for the effect of inputs' complementarity on GM cotton performance is a clear example of this situation. It is important, however, to at least have a picture of the potential interaction among key production inputs (such as labor, mineral fertilizers, and chemical insecticides) and in this context to understand the role and the need for a reliable and affordable source of credit.

WHAT WOULD BE THE EFFECT OF GM ADOPTION ON LABOR DEMAND?

Cotton is a labor-intensive crop. Farmers in Uganda use family labor and quite frequently use hired labor too. As shown in the analysis, family labor is not accounted for in our budget estimations. The use of GM cotton varieties would probably demand higher labor for agricultural practices, mainly for harvesting. Initially, this additional labor for harvesting could be done by family members. This is a strong possibility for low-input users, who make up the majority both in our sample and in Uganda. Another strong possibility is partial adoption, where low-input users would plant GM cotton in part of the plot. This partial adoption may not require additional hired labor.

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[7] Hardaker et al. (2004) refer to uncertainty as "imperfect knowledge" and to risk as "uncertain consequences."

In general, many factors can affect labor demand in GM cultivation. For budget estimations, it can reasonably be assumed that a higher yield will produce a proportional increase in labor demand, although doing so can result in overestimating, because either labor may not be readily available or the household may lack enough financial resources to hire additional labor. In any case, as shown in Table 5.8, yield increases imputed to GM seed are basically due to the efficiency of the technology in abating damage (the damage being the expected yield loss due to bollworm multiplied by GM technology efficiency). If yield shows a positive and perfect correlation to labor use for harvesting, then the relative yield increase can be used as an upper bound on additional labor requirements for harvesting.

Using the average values in Table 5.8 to recalculate partial budgets in Table 5.9, we notice that when potential changes in labor demand are taken into account, the reduction in marginal benefits is more severe under the high technology fee (technology fee 2 in the table). Bt cotton reports the highest reduction in marginal benefits under either technology fee scenario, whereas the organic + Bt scenario reports the lowest reduction. In other words, it is important to take into account the effect of higher labor demand on expected profits. If the producer uses mainly hired labor, it will definitely have an impact on profit margins. It is expected that this type of producer will also invest in other complementary inputs that will contribute to an even better performance of the variety and thus compensate for the hired labor costs and additional investment in other inputs.

WOULD THE USE OF MINERAL FERTILIZERS AUGMENT THE PROFITABILITY OF GM COTTON?

A major factor in cotton production is the availability of adequate and balanced nutrients. Fertilizers are underused in cotton in Uganda, despite the common belief that chemical fertilizers are primarily used for export crops. In general, Yanggen et al. (1998) explained that cotton in Africa south of the Sahara has relatively poor yield response to fertilizers and mediocre profitability. They attribute this behavior to a lack of adequate incentives in terms of yield, price, or expected profit (Kelly 2006). In other words, farmers do not perceive the advantage of using fertilizers, because their use (or increased use) does not necessarily translate into higher yields, better prices, or better profits.

The effect of fertilizers is very complex, because it depends on a number of environmental and management practices. Better cotton performance is the expected result of using chemical fertilizer. However, we do not have enough technical information to make assumptions about soil fertility and its ability to

TABLE 5.9 Sensitivity analysis for complementary inputs

	Bt cotton			HT cotton			Organic + Bt cotton		
Scenario	Margin (US$ per hectare)	Change (%)	B-C ratio	Margin (US$ per hectare)	Change (%)	B-C ratio	Margin (US$ per hectare)	Change (%)	B-C ratio
Baseline									
Technology fee 1	169.33	—	1.50	186.44	—	1.57	188.57	—	1.67
Technology fee 2	42.91	—	1.09	60.02	—	1.13	62.15	—	1.15
Labor for harvesting									
Technology fee 1	158.41	–6.45	1.46	175.00	–6.14	1.52	180.61	–4.22	1.62
Technology fee 2	30.36	–29.25	1.06	48.58	–19.06	1.10	54.19	–12.81	1.13
Fertilizer[a]									
Yield increase of 10%									
Technology fee 1	195.60	15.51	1.54	212.67	14.07	1.61	—	—	—
Technology fee 2	67.39	57.03	1.14	86.25	43.71	1.18	—	—	—
Yield increase of 25%									
Technology fee 1	251.38	48.45	1.66	269.18	44.38	1.73	—	—	—
Technology fee 2	122.93	186.45	1.24	142.76	137.86	1.29	—	—	—
Yield increase of 50%									
Technology fee 1	344.35	103.36	1.83	363.36	94.89	1.90	—	—	—
Technology fee 2	215.49	402.15	1.40	236.93	294.77	1.45	—	—	—
Yield increase of 75%									
Technology fee 1	437.33	158.26	1.98	457.53	145.41	2.04	—	—	—
Technology fee 2	308.06	617.85	1.54	331.11	451.69	1.59	—	—	—
Yield increase of 100%									
Technology fee 1	530.30	213.17	2.10	551.71	195.92	2.17	—	—	—
Technology fee 2	400.62	833.55	1.66	425.29	608.61	1.71	—	—	—
Pesticide[b]									
Technology fee 1 + fertilizer									
Yield increase of 10%	184.08	8.71	1.50	208.31	11.73	1.59	—	—	—
Yield increase of 25%	239.86	41.65	1.61	264.82	42.04	1.71	—	—	—
Technology fee 2 + fertilizer									
Yield increase of 50%	197.52	360.27	1.35	232.57	287.51	1.43	—	—	—
Yield increase of 75%	290.09	575.79	1.49	326.75	444.43	1.57	—	—	—
Yield increase of 100%	382.65	791.67	1.61	420.93	601.35	1.70	—	—	—

Source: Authors' survey data.

Notes: Numbers are rounded estimates. B-C ratio = benefit-cost ratio; Bt = insect resistant; — = not applicable.

[a] These estimations include the costs associated with the additional labor for harvesting.

[b] Fertilizer and labor changes are included. Pesticides control the damage of secondary pests, so the effect of fertilizer is realized.

use the minerals provided by fertilizer. This type of information is location sensitive and, given the high soil diversity and heterogeneous conditions in Africa south of the Sahara, it is difficult to make generalizations. Even the standard fertilizer recommendations are not appropriate for this region, and more site-specific recommendations for increasing productivity are needed (Carr 1993).

The response of the GM crop varieties to fertilization is unknown, and the variability across producers will probably be high. Instead of guessing at the magnitude of this effect, we set targets for yield increases (10, 25, 50, 75, and 100 percent) resulting from fertilizer application. We use the output-nutrient ratio reported in Kelly (2006) to estimate marginal budgets for different yield responses to fertilization. A yield response is the additional yield obtained with one additional unit of fertilizer; yield increases are a percentage change over the baseline. Kelly (2006) reports typical, minimum, and maximum values for a yield response. We use the typical or modal value (5.8) mainly to avoid the influence of outliers.

Table 5.9 presents marginal benefits under different levels of fertilization. These results show that marginal benefits and the benefit-cost ratio improve relative to the baseline for GM cotton even when the target is only a 10 percent yield increase from fertilizer application, and especially when the technology fee is subsidized (technology fee 1). When the technology fee is fully paid by farmers (technology fee 2), investment in fertilizer has to be much higher compared to scenario 1 to obtain comparable benefits. These findings indicate that fertilizer use in cotton production is low partly because of the large (and expensive) amount required to make production profitable. The results highlight the importance of negotiating a fair technology fee and making credit available to farmers so they can pay it.

WOULD GM SEED REDUCE PESTICIDE USE AND INCREASE THE MARGINAL BENEFITS OF COTTON?

The relationship between GM cotton and pesticide use is complicated, especially in the case of Bt cotton. GM cotton is just as vulnerable as any non-GM variety to drought or outbreaks of non-bollworm pests. In China, India, and South Africa, reductions in pesticide use, related mainly to the use of Bt cotton, have been observed. However, there is some evidence that initial reductions in pesticide use have been reversed when insecticides are needed to control secondary non-bollworm pests (Pemsl, Waibel, and Orphal 2004; Glover 2010). As a result, some farmers in China and India who have adopted GM cotton varieties continue to apply excessive quantities of insecticides (Pemsl, Waibel, and Orphal 2004). As in China and India, farmers in Africa have to deal with pesticides of uncertain origin and quality (Pemsl, Waibel, and Gutierrez 2005; Tripp 2009). Thus, as argued by Glover (2010), farmers face a difficult and uncertain set of trade-offs when determining their risk management strategies. As a consequence, these farmers opt to keep using high levels of insecticides. This can happen in Uganda as well.

In Uganda, in contrast with the situation in China or India, our analysis of the production factors shows that neither insecticides nor herbicides are used in optimal quantities (see Table 5.6, damage-control analysis). Under these circumstances, the adoption of Bt cotton is more likely to be accompanied by an increase, rather than a reduction, in the use of insecticides to control secondary pests. To depict this situation, we estimated a partial budget that assumes a 25 percent increase in the use of insecticides to control other nonlepidopteran pests. Because additional insecticide applications will require more labor, we discarded the 25 percent labor-reduction effect originally considered in the baseline estimation (see Table 5.8). The partial budget estimation for Bt cotton also assumed a reduction in insecticide use against lepidoptera.

In this last estimation, insecticides are treated as damage-control inputs, and for this reason we do not assume a yield increase stemming from insecticide use. Insecticides merely control secondary pests so the fertilizer's effect is realized. Marginal benefits are higher than the baseline but lower than just accounting for fertilizer's yield effect. The technology fee is again a key factor that determines not only the magnitude of benefits but also the level of investment in additional inputs needed to make GM cotton production profitable. For most cotton farmers, there are just not enough incentives to invest in high-quality inputs.

WHAT WOULD BE THE ROLE OF RURAL CREDIT?

Given this analysis of complementary inputs, what would be the role of rural credit? The results above only confirm the well-known fact that cotton producers will largely benefit from having access to credit. Kabwe and Tschirley (2007) provide evidence for the validity of this argument in Africa south of the Sahara, a region where (1) cotton production requires substantial use of production inputs, (2) smallholder farmers are typically cash constrained, (3) input markets are weak, and (4) rural credit markets for agriculture are nearly nonexistent.

Poor access to credit may be the main reason farmers are not adopting fertilizer and might not adopt GM seed. The analysis of input-use patterns done by Reardon et al. (1997) concluded that in Burkina Faso, Senegal, and Zimbabwe, the elimination of fertilizer credit and subsidies associated with structural adjustment programs led to sharp reductions in fertilizer use.

Another example is the case of South Africa, where the initial success of Bt cotton in the Makhathini Flats depended heavily on the joint support of the local cotton company and the local credit agency (Gouse et al. 2005; Glover 2010). Baffes (2009), however, warns about the possibility that in Uganda, the decision to grow cotton can reflect the high costs of credit only for some farmers, whereas for other farmers it reflects the absence of alternative sources of cash income. Baffes also concludes that policies based on the assumption that provision of credit is the key constraint are likely to lead to inadequate policy recommendations.

In our sample, about 28 percent of the farmers had access to some source of cash credit, and 55 percent of those with access had to pay interest on the loan, which ranged from 10 to 100 percent. Higher interests were usually linked to smaller loans, which created a clear disadvantage for smallholder and cash-constrained farmers. About 13 percent of the farmers in our sample had access to in-kind loans, receiving seeds or other production inputs to be repaid at harvest. In the history of Ugandan cotton production, there have been several efforts to support farmers with inputs and credit (Baffes 2009), the most recent one being the zonification abandoned in 2006. Given the current situation in Uganda, introducing a technology such as GM crops should be accompanied by setting up rural credit markets or alternative forms of farmer-organized credit that are accessible and affordable to farmers, particularly small producers. When baseline levels of uncontrolled pest damage are high, as in Uganda, GM cotton (namely, Bt cotton) can confer an unconditional yield effect in addition to the stochastic yield effect that is subject to environmental conditions (Lybbert and Bell 2010). This reduction in yield uncertainty could generate conditions that would encourage people, even small producers, to borrow, as well as to lend.

However, lack of credit is not the main constraint for all Ugandan cotton producers. There are areas, particularly in the Northern Region where organic cotton is produced, that are constrained mainly by the limited alternatives to cotton production as sources of cash income. In these areas, farmers' best option is probably to capture the higher prices fetched by organic cotton, although they could still derive benefits from better credit accessibility.

Conclusions and Policy Recommendations

This chapter has addressed the critical question of whether the adoption of GM cotton would make farmers in Uganda better off. A survey was used to collect farm-level information and to compare the profitability of various real and simulated production alternatives. The study evaluated six production alternatives: (1) conventional system, (2) organic system with current farm-gate prices, (3) organic system with a guaranteed premium price, (4) use of Bt cotton seed, (5) use of HT cotton seed, and (6) a hypothetical situation using Bt cotton seed in an organic system. The study also evaluated two scenarios for each of the production alternatives that involved the use of GM seed. In the first scenario, the technology is subsidized: that is, farmers do not pay the full price of the GM seed. In the second scenario, farmers assume the full costs of the technology.

At first glance, the estimated values of cotton profitability in this analysis do not seem to justify investment in a complex technology such as GM cotton. Overall, the simulations show that, with a subsidized technology fee (technology fee 1 in the tables), farmers using Bt and HT cotton varieties will achieve the highest returns, but the profitability of the crop will not increase dramatically compared to conventional or organic systems. If the technology fee has to be fully paid by adopting farmers (technology fee 2), then the adopters will most likely be wealthy farmers who would probably need to increase their investments in complementary inputs. In general, for all types of producers—particularly farmers adopting GM seed—appropriate access to complementary inputs, specifically fertilizer, will help improve the profitability (as measured by the marginal benefits) of cotton production.

Therefore, the government has two clear tasks here. The first one is related to the technology fee and to the need to guarantee that this fee is affordable for cotton producers. This task is crucial, especially if the goal of the technology introduction is to address poverty. The second task is to generate incentives for the provision of rural credit. Independent of the producer type, there is a need for access to an affordable source of credit and thus for access to complementary inputs. Evidence shows that fertilizer and pesticides do not significantly contribute to improved cotton performance. Although most producers interviewed have used some sort of chemical pesticide, few of them used fertilizer, despite its potential. The problem is not availability but mainly affordability. Cotton producers are often cash constrained and need access to some sort of credit to finance the crop campaign. For these producers, profits from cotton production simply do not justify the investment in costly inputs for a highly risky crop. GM cotton contributes to reducing the risks of crop production and thus to increasing the incentives for investment, but credit institutions need to provide access to affordable credit for GM cotton production to achieve the desired production and poverty reduction goals.

In the case of Bt and HT cotton, it is important that farmers are not using significant levels of insecticides and herbicides, and therefore the expected reduction of the use of both types of chemical would be insignificant. It is also important to take into account that if yield losses due to bollworm are lower than those self-reported by farmers (a situation known as "low incidence of the constraints" in the particular year), the profitability of this technology will dramatically decrease. For this reason, it is advisable to introduce Bt/HT cotton technology as a form of insurance, rather than as a way to increase yields. The technology will protect Ugandan farmers against severe or even catastrophic losses, because it targets pests and weeds.

As mentioned in Chapter 3, organic cotton production in Uganda, although unstable, is a growing industry. For this reason, it is important to take into consideration the potential impact of GM cotton adoption on organic production. Therefore, another goal of our study was to obtain a minimum sample of observations that would allow us to draw valid conclusions for the organic cotton sector. This proved to be more challenging than expected, as several of the identified organic producers reported using some amount of chemicals to control biotic damage.

It is possible to compare the profitability of a given year of organic cotton production with that of conventional cotton production using GM seed, but this provides only a partial view of the cotton landscape. Such information is valid for a rapid assessment and can help in decisionmaking, especially in the framework of a regulatory process and the time and budget constraints that this process implies. It is much more significant, but at the same time more challenging, to evaluate the long-term contribution of either an organic or conventional production system to farmers' welfare. This research topic requires further attention.