Bt Cotton in Argentina: Analyzing Adoption and Farmers’ Willingness to Pay

Matin Qaim and Alain de Janvry

Department of Agricultural and Resource Economics
University of California, Berkeley, CA 94720
Contact: M. Qaim (qaim@are.berkeley.edu)

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Abstract

Unlike several other countries, where Bt cotton is being rapidly adopted, in Argentina technology diffusion has been rather slow. Based on recent survey data, it is shown that the technology significantly reduces insecticide applications and increases yields; however, these advantages are curbed by the high price charged for genetically modified seeds. Using the contingent valuation method, it is shown that farmers’ average willingness to pay for Bt cotton is less than half the actual market price. A lower price would not only increase benefits for cotton growers, but could also multiply the profits of the monopoly seed producer, thus resulting in a Pareto improvement. Implications of the sub-optimal pricing strategy are discussed.
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Introduction

Bt (Bacillus thuringiensis) cotton is genetically engineered to make it resistant to major insect pests. It was developed by Monsanto and, as one of the first genetically modified (GM) crop technologies, it became commercially available in the mid 1990s. Since then, the technology has spread rapidly in the US, Australia as well as in several developing countries (James). In Argentina, Bt cotton was released in 1998 by Genética Mandiyú, a joint venture between Monsanto, Delta and Pine Land (D&PL), and the local company Ciagro. Unlike other countries, however, in Argentina the diffusion of Bt cotton has been rather slow up till now. According to official statistics, three years after its introduction, Bt technology only covered about 5% of the national cotton area. This is surprising, in particular when compared to GM soybeans which were adopted almost completely in the country within a similar time frame.

This article analyzes the reasons for the slow adoption of Bt cotton in Argentina and, in doing so, sheds light on the impact of corporate pricing strategies on the dissemination of proprietary innovations. GM crops are still a rather young phenomenon, and their merits and limitations are controversial, especially with a view to developing countries. Detailed empirical studies can help better understand the implications of GM crops under specific conditions. Our analysis is based on a representative survey of 299 cotton farms, including adopters and non-adopters of Bt technology, that was carried out in Argentina in 2001.

The most important precondition for widespread adoption of a new technology is its profitability for farmers. We will show that net benefits for Argentine farmers who adopted Bt cotton are rather small. Although the technology significantly reduces insecticide applications and increases yields, these benefits are curbed by the high price for Bt cotton seeds. Unlike GM soybeans, which are not patented in Argentina and are marketed by different seed companies, Monsanto was granted a national patent over Bt cotton technology, and Genética Mandiyú is the
sole provider of Bt seeds. Farmers have to pay US $103 per hectare for Bt cotton seeds, which is more than four times the price of conventional varieties.

In standard technology adoption studies, the price of the technology is taken to be determined. While this approach is justified for publicly released technologies or when there is competitive pricing, the situation is different when the technology is protected by intellectual property rights (IPRs). Private innovators, endowed with a patent on a technology, will attempt to capture the benefits of their innovation through monopoly pricing (Moschini and Lapan). In a static perspective, this is of course negative for farmers. However, an excessive price as a result of incomplete knowledge of the demand curve or other possible factors can bring about lost profits for the monopolist as well.

We hypothesize that the high price of Bt cotton in Argentina does not only constitute an important adoption constraint for farmers, but that a lower price would also lead to higher company profits, thus resulting in a Pareto improvement. To test this hypothesis we will estimate farmers’ willingness to pay (WTP) for the technology and construct a demand curve for Bt cotton as well as a company profit function. Since farmers’ responses to changes in the price of the technology cannot be observed from market data, we use a contingent valuation (CV) approach. The findings will help to better understand farmers’ behavior with respect to GM crop adoption and to design appropriate technology diffusion and pricing policies in Argentina and other countries.

The paper is organized as follows. The next two sections describe the methodology of the study and the data set. After that we briefly illustrate the process of Bt cotton adoption in Argentina before examining the technology’s farm-level impacts. Then, we present the results of the CV analysis and derive the Bt cotton demand and profit functions. The last section discusses the findings and draws conclusions.
Methodology

In order to estimate farmers’ WTP for Bt cotton, the survey questionnaire included a CV module. Farmers who did not adopt at the current market price were asked whether they would use the technology at a hypothetical lower price which was varied across questionnaires. It is generally agreed that such a dichotomous choice approach yields better results than directly asking for the WTP in an open-ended question, because it provides respondents with a more market-like situation. Using only the response data to the hypothetical prices, however, ignores some potentially useful information. We already know that the particular farmers decided not to adopt Bt cotton at the observed market price of $103 per hectare. Combining the revealed and stated preference information from non-adopters provides us with data that are similar to those obtained in a double-bounded CV survey.\(^1\) Moreover, including the revealed preference data from the current adopters will further enrich the information base. This approach was suggested by Cooper in a study on the adoption of different water quality protection practices. Hubbell, Marra, and Carlson used the methodology to estimate farmers’ WTP for Bt cotton in the US.

The farmers’ decision whether or not to use Bt cotton is modeled in a random utility framework. A farmer adopts when the utility with the technology is at least as great as without it, that is, if

\[(1) \quad U(1, y_1 - P; x) \geq U(0, y_0; x)\]

where 1 indicates the Bt technology and 0 the conventional alternative. \(y_1\) and \(y_0\) are expected profits from Bt and conventional cotton, respectively, and \(P\) is the price of the technology. \(x\) is a vector of household, farm, and contextual characteristics, including productive assets, demographic variables, and institutional and environmental factors. The utility function is only imperfectly observable for the investigator, so that the inequality can be written as

\[(2) \quad V(1, y_1 - P; x) + \epsilon_1 \geq V(0, y_0; x) + \epsilon_0\]

\(^1\) Hanemann, Loomis, and Kanninen showed that the double-bounded approach is statistically more efficient than the single-bounded approach.
where \( V(\cdot) \) is the deterministic part of the utility function, and \( \varepsilon_1 \) and \( \varepsilon_0 \) are i.i.d. random variables with zero means. As is common in CV studies, we assume that \( V(\cdot) \) is linear, that is

\[
V_i = \beta_i' \mathbf{x} + \alpha(\bar{y}_i - \delta_{i1} P)
\]

where \( i = 0, 1 \), \( \alpha \) is the marginal utility of income, and \( \delta_{i1} \) is a Kronecker delta that takes the value of one when \( i = 1 \) and zero otherwise. Equation (2) can then be written as

\[
\beta' \mathbf{x} + \alpha(\Delta\bar{y} - P) \geq \epsilon
\]

where \( \beta' \mathbf{x} = \beta_1' \mathbf{x} - \beta_0' \mathbf{x} \), \( \Delta\bar{y} = \bar{y}_1 - \bar{y}_0 \), and \( \epsilon = \epsilon_0 - \epsilon_1 \). Unfortunately, we cannot observe expected changes in profit caused by the technology. However, we suppose that this variable can be explained by other farm characteristics, so that \( \Delta\bar{y} \) is implicitly included in the vector \( \mathbf{x} \). In our WTP context, \( \alpha \) takes a value of one. Assuming that \( \epsilon \) is distributed \( \mathcal{N}(0, \sigma^2) \), the decision to adopt Bt cotton at price \( P \) can be expressed in probability form as

\[
\text{Prob}(WTP \geq P) = \text{Prob}[\epsilon \leq \beta' \mathbf{x} - P] = \Phi \left( \frac{\beta' \mathbf{x} - P}{\sigma} \right) = 1 - \Phi \left( \frac{P - \beta' \mathbf{x}}{\sigma} \right).
\]

In a single-bounded approach, equation (5) could be used to estimate the WTP of non-adopters based on the responses to the hypothetical price bids \( P^* \), which are smaller than the currently observed market price \( P^M \). In our framework, however, we need to account for the fact that the answer to the hypothetical price is conditional upon a “no” response to \( P^M \). Also including the current adopters (i.e., those who said “yes” to \( P^M \), there are three possible responses:

\[
\text{Prob}(yes) = \text{Prob}(WTP \geq P^M),
\]

\[
\text{Prob}(no/yes) = \text{Prob}(WTP \leq P^M) - \text{Prob}(WTP \leq P^*),
\]

\[
\text{Prob}(no/no) = \text{Prob}(WTP \leq P^*).
\]

Correspondingly, the log-likelihood function for this WTP model is
\[
\ln L = \sum_{i=1}^{n} I^y_i \ln \left[ 1 - \Phi \left( \frac{P^M - \beta' x}{\sigma} \right) \right] + I^{NY} \ln \left[ \Phi \left( \frac{P^M - \beta' x}{\sigma} \right) - \Phi \left( \frac{P^* - \beta' x}{\sigma} \right) \right] \\
+ I^{NN} \ln \left[ \Phi \left( \frac{P^* - \beta' x}{\sigma} \right) \right]
\]

(7)

where the \( I \) symbols denote binary indicator variables for the three response groups (\( i \) subscripts suppressed). ² Unlike maximization of a regular probit likelihood function, which yields parameter estimates only up to a factor of proportionality (i.e., \( \beta/\sigma \)), the \( \beta \) coefficients in equation (7) can directly be interpreted as the marginal effect of the \( x \) variables on WTP in dollar terms.

Using these results, we can predict the share of farmers likely to adopt Bt cotton (ASHARE) at different price levels. For constructing a demand curve, however, we additionally need information on the area that adopting farmers would cultivate with Bt cotton at the price \( P^* \). This was also asked during the survey in connection with the CV questions. Following Cooper and Hubbell, Marra, and Carlson we assume that the proportion of Bt hectares to total cotton hectares on a farm (\( BTPROP \)) is a function of farm characteristics and the price of the technology (\( P = P^M \) or \( P^* \)) so that

\[
BTPROP = \gamma' x + \eta P + u
\]

(8)

where \( u \) is a random error term with mean zero. Although this area proportion model can be estimated using ordinary least squares (OLS), a direct estimation might lead to biased results. \( BTPROP \) is only observed for the current and contingent adopters, while, for those farmers who responded “no” to the hypothetical price bid, the dependent variable is missing. We use the two-step Heckman estimation procedure to correct for this non-random selection bias (Heckman). In the first step, we calculate the Mills ratio from the WTP model which is then included as a right-hand-side variable in OLS regression of equation (8). ³ \( BTPROP \) is not censored at one, because

² An implicit assumption behind combining adopters and non-adopters in one model is that both groups have the same utility function with identical coefficients (cf. Adamowicz, Louviere, and Williams). Whether this holds true in our case cannot be established a priori. Cooper, however, argued that data pooling might be advantageous even if the groups are somewhat different, because the actually observed data from the adopters help to smooth out possible biases from the CV responses of non-adopters.

³ Since our WTP model estimates \( \beta \) rather than \( \beta/\sigma \), we divide all parameters by \( \sigma \) for calculation of the Mills ratio.
respondents could state the contingent Bt area to be larger than their present total cotton area. Since heteroscedasticity between current and contingent adopters is possible, we use the White estimator for the second step regression.

The total Bt cotton demand in hectares ($BTDEM$) at a given price $P$ can then be predicted as

$$BTDEM(P) = ASHARE(P) \times BTPROP(P) \times TOTCOT_i,$$

where $TOTCOT_i$ is the total cotton area in the country observed in the reference year $t$. Although $TOTCOT_i$ is a constant, we do not assume that the total crop area is completely independent of $P$. As $BTPROP$ can be bigger than one, $BTDEM$ can be bigger than $TOTCOT_i$, which would lead to an increase in the total cotton area. This is conceivable if $P$ is sufficiently small. Given the current high price of Bt seeds and low adoption levels, it is rather unlikely that further price increases would induce an opposite development, that is, a significant decrease in the national cotton area.

The monopolist’s profit $\pi$ as a function of the technology price is simply

$$\pi(P) = (P - C) \times BTDEM(P),$$

where $C$ is the marginal cost of producing Bt seeds, which is assumed to remain constant, independent of volume produced.

**Data**

An interview-based survey of 299 cotton farms was carried out in 2001 in collaboration with Argentina’s *Instituto Nacional de Tecnología Agropecuaria* (INTA). The survey covered the two major cotton-growing provinces, Chaco and Santiago del Estero, which together account for 88% of the Argentine cotton area (Pellegrino). As the number of Bt users is still comparatively small, we employed a stratified random sampling procedure, differentiating between adopters and non-adopters of the technology. Complete user lists were provided by Genética Mandiyú, whereby users were defined as those farmers who had used Bt cotton at least once during the last two
growing seasons. The total sample consists in 89 adopters (about 60% of all adopters in the country) and 210 non-adopters. A check with official statistics (SAGPYA) and census data showed that the sub-sample of non-adopters is representative of the Argentine cotton sector in terms of average farm sizes and cultivation practices.

Apart from eliciting general farm, household, and contextual characteristics, the survey included detailed questions about input-output relationships in cotton cultivation for two growing seasons – 1999/2000 and 2000/2001. As all Bt adopters had also cultivated at least some conventional cotton, they were asked the same questions for both their Bt and conventional plots. Furthermore, the questionnaire covered aspects of farmers’ perceptions about Bt technology. Table 1 shows different characteristics of users and non-users. In order to account for heterogeneity in the Argentine cotton sector, we subdivided the non-adopters into three groups according to overall farm size. Minifundios are farms with less than 20 hectares, small farms have between 20 and 90 hectares, and medium and large farms have more than 90 hectares. These groups account for 60.4%, 25.3%, and 14.3% of all Argentine cotton producers, respectively (SAGPYA).

Minifundios are resource-poor farmers who cultivate cotton for sale, alongside a number of food crops mostly for home consumption. All agricultural operations in this group are usually carried out manually or by means of animal traction. The small farms also have to be classified as predominantly resource-poor. In contrast, the medium and large-scale farmers are comparatively better off. Although the majority of these farms can still be labeled family businesses, farmers often live in the nearby town and employ one or more permanent workers. As can be seen from table 1, the Bt adopters are fairly representative of the group of medium and large farms.

The Process of Bt Cotton Adoption

Historically, cotton breeding in Argentina has been dominated by the public sector (Poisson and Royo). Until the late 1990s, varieties developed by INTA’s cotton breeding program accounted
for over 90% of the germplasm available on the domestic seed market. These varieties are well adapted to the local agroecological conditions, but, as all conventional cotton cultivars, they are susceptible to lepidopteran insects.

Bt cotton provides genetic resistance to the cotton bollworm complex (Helicoverpa gelotopoeon and Heliothis virescens), the cotton leafworm (Alabama argillacea), and the pink bollworm (Pectinophora gossypiella), all of which are major insect pests in Argentina. In 1998, Genética Mandiyú commercialized the first Bt cotton variety, NuCotn 33B, in the country. A second Bt variety, DP 50B, was released in 2000. Both varieties were not specifically developed for Argentina but have also been commercialized by Monsanto and D&PL in the US and a number of other countries.

Generally, the Argentine seed law allows farmers to reproduce their cotton seeds for one season before they have to buy fresh, certified material. However, for Bt cotton, Genética Mandiyú introduced special purchase contracts prohibiting the use of farm-saved seeds. Also, these contracts specify requirements for non-Bt refuge areas and state that the cotton produced may only be handled by certain authorized gins. As the contract requirements go far beyond the seed law regulations, they are not enforced by public authorities. Farmers have to permit field inspections by company officials for monitoring purposes.

Table 2 shows the development of the Bt cotton area in Argentina since 1998. Although until 2000/01 the Bt area increased steadily, three years after the introduction of the technology its share in the total cotton area was still only 5.4%. This is much lower than adoption rates in other countries where Bt cotton was commercialized (James). In the 2001/02 growing season, the Bt area fell significantly along with the sharp overall decline in national cotton production. This is a reflection of the current low world market price for cotton. As Argentine cotton farmers do not receive price subsidies, the area elasticity with respect to international prices is high. Furthermore, the overall economic crisis in the country might have influenced farmers’ planting choices. The cotton area in 2001/02 was the lowest in the last 30 years. But, even at low world
market prices, local experts reckon that the area will again reach a level of around 400,000 hectares in the medium run.

Table 2 only shows the official Bt area, that is, plots planted with Bt seeds that farmers acquired legally through Genética Mandiyú. While relatively small in the first years, illegal Bt cotton plantings became significant in 2001/02. According to unofficial estimates, the total Bt cotton area in that season might have been around 50,000 hectares, more than five times the official area planted. We take this as an indication that the outcome of the diffusion strategy is rather disappointing from the private sector point of view. Illegal Bt cotton areas include plots on which previous official adopters use farm-saved Bt seeds. However, discussions with farmers and input providers revealed that there is also a sizable black market for Bt seeds in Argentina. In our sampling framework, only official users were defined as Bt adopters.

Table 3 provides further insights into the pattern of Bt adoption over time. The bold values on the first diagonal of the matrix show the number of official adopters included in our sample in a particular year. Above the diagonal are those who already used the technology in previous years, whereas the values below the diagonal indicate how many farmers continued to use it in following years. The dropout rate is significant in all the growing seasons. On average, only half of the farmers who used Bt cotton in one year decided to also use it in the following year. For comparison: Monsanto states that grower satisfaction with Bt cotton in the US is over 95%. However, in Argentina there are also farmers who abandon and adopt again after a one or two years break. Some of those farmers might use farm-saved Bt seeds in the meantime, but, based on our interviews, others apparently do not. These patterns suggest that Bt adoption in Argentina is not a long-term decision, but rather one which is reviewed every year anew.

**Farm-Level Effects of Bt Cotton**

To analyze the farm-level effects of Bt cotton in Argentina, we compare gross margins per hectare with and without use of the technology. Since for Bt adopters data are available for both
their Bt and conventional plots, we confine the comparison to this sub-sample. This approach helps to filter out the influence of other, non-Bt related factors on gross margins. Pest pressure and economic conditions may vary from year to year, so that it is instructive to contemplate both growing seasons for which data were collected. Differences in soil characteristics which might bias the analysis were accounted for by excluding plots with very high and very low soil quality. For that reason, the number of plot observations is slightly smaller than the number of adopters in each growing season. The results are shown in table 4.

As expected, Bt technology reduces the expenditure on insecticides. In 1999/00, the average number of insecticide applications was reduced by 2.3, whereas in 2000/01 it was reduced by 2.4. Moreover, there is a significant increase in the yields that farmers obtained in both seasons. As the conventional germplasm is actually better adapted to local conditions than the commercialized Bt varieties, it can be assumed that this is an avoided pest-related yield loss rather than a real gain in yield potentials. A significant difference in the cost for machinery and labor cannot be observed. Slightly lower expenses for the application of pesticides are counterbalanced by elevated harvesting costs on account of higher yields. Yet the most significant cost change is due to seeds. Bt seeds add to total production cost by one-third and almost double the expenditure for the bundle of purchased inputs.\footnote{For small farms, Bt cotton seeds would almost triple, and for minifundios even quadruple, the total cost of purchased inputs (see table 1).}

Altogether, average gross margins are higher with Bt technology in 1999/00 and 2000/01. Owing to high variation across farms, however, these increases are not statistically significant, and they are much lower than the benefits in other countries.\footnote{For instance, in Mexico, the net benefit of Bt cotton was US $295 per hectare on average for 1997 and 1998 (Traxler et al.). In China, Pray et al. reported per hectare benefits of around $400 for 1999. Elena carried out a study for Argentina based on data collected by Monsanto for the 1999/00 season. Her results are similar to ours for the same season.} Also, mean values hide the fact that, in both seasons, around 40% of the Argentine Bt cotton adopters experienced a decrease in gross margins. This result explains the significant dropout rates in adopters shown in the previous section.
The rise in total production cost associated with Bt technology intensifies the economic risk that farmers face. The net benefits mainly depend on the additional revenues, which are a function of yield gains and cotton prices. A downward trend in world market prices, as currently observed, therefore lessens the technology’s comparative advantage. Although yield increases and pesticide reductions are similar in both growing seasons, the absolute gain in gross margins is much lower in 2000/01 because of the decline in cotton prices. Indeed, the gain in 2000/01 would have been significant at the 5% level had cotton prices remained unchanged. The effects of output price variation can certainly look different in settings where cotton is produced with input intensities that are higher than those in Argentina. Needless to say, lower prices for Bt seeds could also change the situation. This is reflected in the rising demand for Bt seeds from the black market, which are sold at around $35-40 per hectare.

As was mentioned in the previous section, the Argentine seed law allows the reproduction of cotton seeds for one season, a practice which Genética Mandiyú tries to prevent for Bt cotton through special contracts. Nevertheless, some farmers might implicitly consider the purchase of Bt seeds as a two-year investment. Based on very limited data that we collected on illegal Bt plots, own reproduction of seeds does not seem to affect the technology’s potential to a significant extent. Splitting the seed price by two and adding the opportunity cost associated with seed saving, we calculated additional crop budgets. Interesting to note is that, under these assumptions, Bt technology would still increase total per hectare production cost. But net benefits would be considerably larger. Had farmers bought Bt cotton in 1999/00 and used farm-saved seeds in 2000/01, average gains in gross margins would have been around $85 and $52, respectively.

**Willingness to Pay for Bt Cotton**

In order to estimate the WTP for Bt cotton in Argentina, non-adopting farmers were asked whether they would use the technology at a hypothetical price lower than the current price of
$103 per hectare. Price bids were varied across farmers. Values between US $90 and $25 were randomly assigned in $10 intervals. $25 is the average competitive price of conventional, certified seeds so that this value theoretically represents a technology premium of zero. However, because not all farmers buy certified seeds every year, the perceived premium might be higher than this.

As was shown in previous sections, defining adopters and non-adopters is not a straightforward procedure because farmers make the adoption decision every year anew. Since our survey was carried out in 2001, we decided to take the 2000/01 cotton growing season as the reference for the WTP analysis; that is, farmers who used the technology in this particular season were defined as adopters. Sixteen farmers who used Bt cotton in 1999/00 but not in 2000/01 were left out of the analysis. Including them in the group of non-adopters might bias the results due to the stratified sampling procedure.

A significant proportion of farmers was not familiar with Bt cotton (64% of the non-adopters). Therefore, at first we carry out a probit analysis in order to identify the variables explaining whether or not a farmer knows the technology (Bt knowledge model). The CV approach, however, can also be used for the evaluation of goods which are hitherto unknown to the respondents if the product attributes are presented objectively (Cameron and James). Both technical and regulatory details associated with Bt were explained to farmers who did not know the technology. Then these farmers were asked whether they would use the technology at the current market price before confronting them with a hypothetical bid.

Explanatory variables considered in the econometric models are defined in table 5. Observations with missing variables were left out of the analyses. Accordingly, the sample for the WTP model consists in 204 non-adopters and 70 adopters. As farm assets, we only consider the cultivable area owned, because other assets are very closely correlated with this variable. Relaxing the linearity assumption we also include the squared value of area into the models.

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6 Farmers in Argentina usually include the value-added tax of 21% when stating input prices. The actual price bids in the questionnaires therefore ranged from $110 to $30.
where empirically justified. Among institutional characteristics, we have dummies for the farmer’s major source of information related to all kinds of innovations in cotton. Public sources include INTA’s agricultural extension service, cooperative engineers, and public media. Private sources are agricultural input companies, merchants, and other private agents. The reference group is composed of farmers who mainly rely on neighbors and other unofficial sources for new information.

Northern Chaco is a dummy that identifies farms located in the departments of San Martín and Güemes. These departments receive erratic below average precipitations and are mainly characterized by very small farms. Thus, apart from climatic factors, northern Chaco to some extent captures neighborhood effects that might play a role in the spread of innovations. The variable insecticide cost quantifies the dollar amount that farmers spend on controlling Bt target pests (i.e., bollworm complex, leafworm, and pink bollworm). Because it could be expected that insecticide cost is endogenous, we carried out Hausman specification tests for our three models, using farmers’ statements on pest infestation levels in 1999/00 and 2000/01 as instrumental variables. For the Bt Knowledge and WTP models, the $\chi^2$ test statistics are actually negative (–2.69 and –4.72, respectively), and for the area proportion model, the test statistic is 0.07. Based on these values, we reject the hypothesis that insecticide cost is correlated with the error terms in all cases. The estimation results are shown in table 6.

Most of the coefficients in the Bt knowledge model show the expected signs. Larger agricultural areas and better education increase the probability of knowing the technology. The effect of a credit constraint is negative, which indicates that access to factors of production is correlated across markets. Interestingly, both source-of-information variables also have significantly negative coefficients, meaning that those farmers who primarily rely on official public or private sources for obtaining information are less likely to know Bt cotton technology. Indeed, Genética Mandiyú itself basically targets a comparatively small group of large-scale farmers, and public extension agents have not yet been involved in dissemination efforts. Those
farmers who know the technology often learned about it from neighbors, whereby farmers in northern Chaco appear to be at an information disadvantage.

The WTP model also shows a significantly positive effect of cultivable area. On average, each additional hectare on a farm increases the WTP for Bt cotton seeds by 8 cents. Although the technology as such is totally divisible, conclusion of the purchase contracts and its compliance have to be seen as invariable transaction costs which might lead to a bias toward larger farms. Furthermore, smallholder farmers sometimes receive free or subsidized cotton seeds from their municipality, a circumstance which unquestionably reduces their WTP for Bt seeds. The negative coefficient for area squared indicates that the added WTP per hectare is slightly diminishing at larger farm sizes.

Albeit not highly significant, education has a positive effect, suggesting that better educated farmers can derive higher benefits from Bt cotton than their less educated counterparts. Given the comparatively low amount of information available to most farmers, this should not come as a surprise. The coefficients for the source-of-information variables confirm that first-hand technical information can increase the WTP. A similar conclusion can be drawn from the positive parameters for the number of years that a farmer knows Bt and the location variable northern Chaco (compare to the sign in the Bt knowledge model).7

The influence of a credit constraint is clearly negative. Although cotton growers rarely use monetary credit to purchase inputs, limited access to financial markets is often associated with a higher level of risk aversion. This can certainly discourage the adoption of expensive seed technology. As expected, insecticide expenditures have a positive effect. The coefficient indicates that an additional dollar spent on chemicals to control Bt target pests increases the WTP by 57

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7 To many of the farmers in northern Chaco, Bt cotton had to be explained during the survey. Given that, ceteris paribus, the WTP in this region is considerably higher than elsewhere, one could expect that the interviews might have biased the results upward. We tested this possibility by maximizing the likelihood function in equation (7) only for those farmers who did not know the technology previously. Although somewhat less efficient due to the smaller sample size, the results are very similar to those shown in table 6. The mean WTP for unaware farmers is lower than the total sample mean, which is consistent with their particular farm and household characteristics. Hence, it does not appear as if the technology explanations during the interviews caused any significant bias.
cents. That this value is significantly different from one implies that farmers do not consider Bt a perfect substitute for chemical insecticides. One reason might be that Bt is an ex ante control measure. That is, the expenditure occurs early on in the crop cycle, before knowing the pest pressure, whereas chemical insecticides can be purchased at a later stage according to actual needs. Control over plots with better soil quality increases the WTP, which is probably due to higher expected yield gains.

Using predictions from this model and taking sampling weights into account, the mean WTP for Bt cotton in Argentina is US $48.99 per hectare, less than half the actual price of $103.\(^8\) Furthermore, we calculated values separately for the three farm groups mentioned above. The mean WTP for minifundios is $38.19, for small farms it is $51.15, and for medium and large farms it is $90.77. Interestingly, these values are similar to the farm groups’ current overall expenditures for purchased inputs. The estimated share of farmers adopting at different price levels is depicted in figure 1. For the minifundios and small farms, the adoption curves are fairly steep until a price level of about $60, after which they gradually bottom out. The curve for the medium and large-scale growers only starts to flatten at around $100.

**Demand and Company Profit Functions**

Table 6 above also shows the results of the area proportion model described in equation (8). The goodness-of-fit of this model is not as good as that of the other two models. Many parameters are not statistically significant. Yet, the coefficient of the price bid is significant and negative, indicating that not only more farmers would adopt at lower technology prices but that adopters would also plant a higher proportion of their area to Bt cotton. Education has a positive influence on the Bt proportion, which could be expected given the earlier results. Indeed, the t-statistic for

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\(^8\) Subtracting the seed cost, the mean WTP is equivalent to a technology premium of around $24 per hectare. For comparison, Hubbell, Marra, and Carlson estimated that cotton farmers in southern US states are willing to pay a Bt markup of $74 per hectare on average.
the coefficient of the Mills ratio confirms that non-random selection bias would have been an issue in a simple, one-step OLS regression.

The information from this model was used to predict average Bt area proportions of current and contingent adopters at different price levels. Again, this was done separately for the three farm groups taking sampling weights into account. By applying the formula in equation (9) we derive the Bt cotton demand curves shown in figure 2. These computations are based on the national cotton area in 2000/01 and farm group area shares as given in SAGPYA. The aggregate function is simply the sum of the individual demand curves. It predicts the actual 2000/01 adoption level (22,000 ha) at a price of $103 pretty well. As can be seen, the price responsiveness of the Bt area is high: at the current market price, the aggregate demand curve has a point elasticity of –4.7; at a price of $95, the elasticity is –9.9. At lower price levels, the price responsiveness declines, and below $50 (approximately the average WTP), demand gets inelastic with an absolute value smaller than one.

Having specified the demand curve for Bt cotton in Argentina, we now turn to our hypothesis that lower technology prices would result in a Pareto improvement. It is obvious that the net benefits for farmers would increase with lower prices. But what about the benefits for Genética Mandiyú, the technology-supplying joint venture? To answer this question we need to analyze the company’s profit function, which we derive by subtracting the cost of producing Bt seeds from total revenues at different price levels (see equation (10)). The marginal cost of producing Bt seeds is constant in relevant dimensions: around $25 per bag, the amount needed to sow one hectare of cotton. This does not include the research and development (R&D) expenditures borne by Monsanto and D&PL, because – as was mentioned before – the varieties available so far were not specifically developed for Argentina. But even if they were, once made, R&D expenditures have to be considered as sunk costs so that they should not influence output or pricing decisions. The profit function is also shown in figure 2.

9 In late 1990s, Genética Mandiyú established new production and processing facilities with an annual capacity of up to one million bags of Bt seeds.
At the current price, the company profit is around $1.7 million. The profit increases steeply with decreasing prices until it reaches its maximum at a price level of $65. At this price we predict a Bt cotton area of 156,000 hectares and a company profit of $6.3 million.\(^\text{10}\) These findings clearly confirm our premise that the current pricing strategy is sub-optimal. Although the absolute numbers would change, this general statement also holds if the total national cotton area is smaller than in 2000/01. For illustration we carried out the computations assuming the cotton area in 2001/02. Also for this growing season, the models predict the official Bt cotton area very well, and the profit-maximizing seed price would once again be at $65 per hectare.

Of course, our assumption of constant marginal costs for the production and dissemination of Bt seeds could be questioned. When more and more farmers, including smallholders, were to adopt the technology, the cost of monitoring and strict contract enforcement would probably rise progressively. So the company might see the large-scale producers, whose WTP is higher anyway, as their main target group. However, even in the present situation, contract enforcement is very limited, and it is unlikely that the relative extent of illegal plantings would increase with lower prices. Therefore, neglecting monitoring costs appears to be a reasonable approach in this particular context.

**Discussion and Conclusions**

This paper has analyzed constraints to the adoption of Bt cotton in Argentina. Although the technology was already commercialized in 1998, the survey carried out in 2001 revealed that there is still only limited awareness among cotton growers, especially smallholder farmers. Bt cotton is supplied by one single joint venture, Genética Mandiyú, which is dominated by foreign companies. Larger information campaigns have not been carried out so far. Even local public sector extension agents have inadequate knowledge about details of the technology. A more

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\(^\text{10}\) Figures 1 and 2 reveal that at a price of $65 mostly the medium and large-scale growers would adopt, causing a change in relative income distribution. However, in absolute terms, minifundio and small farms would not be worse off, because Argentina is a small and open cotton-producing economy, so that technology adoption has no effect on the output price.
widespread dissemination of relevant information could definitely promote the process of technology diffusion.

The major adoption constraint, however, is the high price of Bt seeds. Farmers have to pay $103 per hectare, which is more than double the total cost that average cotton growers spend on purchased inputs. In many cases, the price markup outweighs the monetary benefits associated with higher yields and lower insecticide costs. It was shown that the farmers’ average willingness to pay for Bt cotton is less than half its actual price. Accordingly, the demand curve is very elastic at higher price levels. Yet, the analysis also revealed that the current price is almost 60% higher than the level that would maximize the monopolist’s profits. At the optimal price level, company profits could be about 3.7 times higher than they are today.

Apart from foregone economic gains for farmers and the company, the sub-optimal price level causes negative externalities. On the one hand, it entails unfavorable publicity, because it backs biotech critics in their argument that GM crops are too expensive for farmers in developing countries. On the other hand, excessive technology prices strengthen the incentive to cheat. Therefore, the widespread cultivation of illegal Bt seeds in Argentina has to be seen as a direct outcome of the corporate pricing strategy. Although cheap, illegal seeds can augment the benefits for cotton growers in the short term, the private sector’s inability to generate profits will detain technological progress in the medium and long term. Furthermore, unofficial Bt cotton plantings are likely to increase the speed of resistance development in pest populations, because proper refuge areas are rarely maintained.

A price of $103 per hectare is equivalent to a technology premium of $78. This is approximately the same as what US farmers have to pay for Bt cotton. A possible explanation for the observed price level would therefore be that Monsanto and D&PL simply transferred the US markup to Argentina. Such a strategy, however, would disregard the fact that cotton growing conditions in Argentina are different from those in the US. Argentina is a low-cost cotton producing country and pest infestation levels are generally less severe than in the US.
Furthermore, the government does not provide output price subsidies for cotton. Hence, the value of Bt cotton is lower for Argentine farmers than for their US counterparts on average. The logical consequence should be differential pricing. This is already implemented in Mexico, for instance, where Bt cotton prices vary across domestic regions (Traxler et al.).

It is actually implausible that large international companies would set a price which is far away from its profit-maximizing level for four consecutive years only due to limited knowledge. Rather it is likely that the price for Bt cotton is partly determined by factors outside of Argentina. Monsanto and D&PL are global players, so that pricing in one country probably has to be seen as part of a broader strategy. If foregone revenues in one country are offset by higher profits in another – potentially more important – country, setting a locally sub-optimal price may be a rational choice. Our argument that a lower price for Bt cotton would lead to a Pareto improvement is strictly confined to Argentina and might have to be revised when considering the global markets of multinationals.

A possible argument against a more widespread international price discrimination may be the influence of the US farm lobby which fears that domestic producers might suffer competitive disadvantages. Monsanto is already under pressure at home because its GM soybean technology is sold more cheaply in Argentina than in the US (GAO). A globally uniform pricing strategy for proprietary GM crops, that responds to the demands of rich country farmers, would be bad news for developing countries. Nor would it serve the intention of the US farm lobby. As was argued above, an official price which is unadjusted to local conditions inspires the emergence of black markets for cheap illegal seeds, unless this can be prevented through effective legal enforcement mechanisms or inbuilt genetic use restrictions. A more detailed analysis of the forces behind global corporate pricing strategies in GM seed markets is beyond the scope of this paper. It would, however, be an interesting topic for future research.
References


Table 1. Selected Farm and Cotton Cultivation Characteristics in 2000/01

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Minifundio (n = 126)</th>
<th>Small (n = 47)</th>
<th>Med. and Large (n = 37)</th>
<th>Bt Adopters (n = 89)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cultivated area (ha)</td>
<td>9.95 (10.40)</td>
<td>42.66 (48.08)</td>
<td>1,061.89 (3,041.36)</td>
<td>1,183.74 (1,400.02)</td>
</tr>
<tr>
<td>Cotton area (ha)</td>
<td>4.64 (2.15)</td>
<td>19.70 (5.58)</td>
<td>482.38 (1,451.66)</td>
<td>463.58 (544.02)</td>
</tr>
<tr>
<td>Seed cotton yield (kg/ha)</td>
<td>1,020.04 (421.75)</td>
<td>1,239.04 (474.97)</td>
<td>1,516.76 (432.60)</td>
<td>1,591.82 (483.09) b</td>
</tr>
<tr>
<td>No. of insecticide applications</td>
<td>2.89 (1.94)</td>
<td>2.96 (2.06)</td>
<td>4.46 (1.45)</td>
<td>4.95 b</td>
</tr>
<tr>
<td>Total cost of purchased inputs ($/ha)</td>
<td>31.91 (23.08)</td>
<td>52.79 (23.65)</td>
<td>81.94 (29.69)</td>
<td>110.15 b</td>
</tr>
<tr>
<td>Mechanized harvest (%)</td>
<td>1.59</td>
<td>48.94</td>
<td>81.08</td>
<td>97.75</td>
</tr>
</tbody>
</table>

a 73 adopters in 2000/01 and 29 in 1999/00.

b These figures refer to the conventional cotton plots of Bt adopters.
Table 2. The Diffusion of Bt Cotton

<table>
<thead>
<tr>
<th></th>
<th>1998/99</th>
<th>1999/00</th>
<th>2000/01</th>
<th>2001/02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total national cotton area (ha)</td>
<td>750,930</td>
<td>331,890</td>
<td>409,950</td>
<td>169,000</td>
</tr>
<tr>
<td>Bt cotton area (ha)</td>
<td>5,500</td>
<td>12,000</td>
<td>22,000</td>
<td>9,000</td>
</tr>
<tr>
<td>Bt in percent of total national area</td>
<td>0.7</td>
<td>3.6</td>
<td>5.4</td>
<td>5.3</td>
</tr>
<tr>
<td>Average Bt area per adopter (ha) a</td>
<td>93.6</td>
<td>109.6</td>
<td>153.8</td>
<td>118.4</td>
</tr>
<tr>
<td>Bt in percent of total cotton area on farm a</td>
<td>15.7</td>
<td>34.9</td>
<td>50.8</td>
<td>41.8</td>
</tr>
</tbody>
</table>

a These figures are results from the farm survey.

Sources: ASA, Pellegrino, industry estimates, and farm survey.

Table 3. Matrix of Bt Adopters in Survey Sample

<table>
<thead>
<tr>
<th>Adopters in 1998/99</th>
<th>Adopters in 1999/00</th>
<th>Adopters in 2000/01</th>
<th>Adopters in 2001/02</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>6</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>29</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>13</td>
<td>73</td>
<td>37</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>37</td>
<td>48</td>
</tr>
</tbody>
</table>
### Table 4. Effects of Bt Cotton on Gross Margins (in US$/ha)

<table>
<thead>
<tr>
<th></th>
<th>1999/00</th>
<th>2000/01</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Bt</td>
</tr>
<tr>
<td></td>
<td>($n = 22$)</td>
<td>($n = 20$)</td>
</tr>
<tr>
<td></td>
<td>Mean (Standard Deviation)</td>
<td>Mean (Standard Deviation)</td>
</tr>
<tr>
<td>Seed cotton yield (kg/ha)</td>
<td>1,535.46 (370.89)</td>
<td>2,070.00** (613.96)</td>
</tr>
<tr>
<td>Gross revenue</td>
<td>409.44 (138.82)</td>
<td>544.53** (210.47)</td>
</tr>
<tr>
<td>Variable cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed</td>
<td>14.99 (7.71)</td>
<td>105.43** (11.97)</td>
</tr>
<tr>
<td>Insecticdes</td>
<td>31.85 (10.55)</td>
<td>17.12** (10.79)</td>
</tr>
<tr>
<td>Other inputs</td>
<td>46.63 (16.28)</td>
<td>48.58 (15.11)</td>
</tr>
<tr>
<td>Own machinery</td>
<td>87.51 (40.78)</td>
<td>91.79 (48.74)</td>
</tr>
<tr>
<td>Hired labor and custom operations</td>
<td>57.88 (63.49)</td>
<td>66.68 (83.08)</td>
</tr>
<tr>
<td>Commercialization</td>
<td>24.18 (5.84)</td>
<td>32.60** (9.67)</td>
</tr>
<tr>
<td>Total variable cost</td>
<td>263.04 (48.05)</td>
<td>362.20** (72.52)</td>
</tr>
<tr>
<td>Gross margin</td>
<td>146.40 (122.07)</td>
<td>182.32 (167.08)</td>
</tr>
</tbody>
</table>

* Significantly different from the value of conventional cotton at 10% level (one-sided t-test).
** Significantly different from the value of conventional cotton at 5% level (one-sided t-test).
<table>
<thead>
<tr>
<th>Variable</th>
<th>Non-Adopters</th>
<th>Adopters</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n = 204)</td>
<td>(n = 70)</td>
<td></td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>SD</strong></td>
<td><strong>Mean</strong></td>
</tr>
<tr>
<td>Area (cultivable area owned in ha)</td>
<td>45.00</td>
<td>101.94</td>
</tr>
<tr>
<td>Education (farmer’s number of years in school)</td>
<td>5.41</td>
<td>2.81</td>
</tr>
<tr>
<td>Age (farmer’s age in years)</td>
<td>49.45</td>
<td>11.55</td>
</tr>
<tr>
<td>Credit constraint (dummy)</td>
<td>0.88</td>
<td>0.32</td>
</tr>
<tr>
<td>Public information source (dummy for major source)</td>
<td>0.54</td>
<td>0.50</td>
</tr>
<tr>
<td>Private information source (dummy for major source)</td>
<td>0.23</td>
<td>0.42</td>
</tr>
<tr>
<td>Time that farmer knows Bt (number of years)</td>
<td>0.65</td>
<td>1.01</td>
</tr>
<tr>
<td>Northern Chaco (dummy for farms located in northern Chaco)</td>
<td>0.27</td>
<td>0.45</td>
</tr>
<tr>
<td>Insecticide cost (in $/ha) (^a)</td>
<td>10.68</td>
<td>9.10</td>
</tr>
<tr>
<td>High soil quality (dummy for above average soil quality)</td>
<td>0.27</td>
<td>0.45</td>
</tr>
</tbody>
</table>

\(^a\) This is a 1999/00-2000/01 average. For adopters, the figure refers to their conventional plots. Only the cost of insecticides used against Bt target pests is considered.
### Table 6. Model Results

<table>
<thead>
<tr>
<th>Variables</th>
<th>Bt Knowledge Model (n = 289)</th>
<th>WTP Model (n = 274)</th>
<th>Area Proportion Model (n = 146)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>t-statistic</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.205</td>
<td>-0.24</td>
<td>21.808</td>
</tr>
<tr>
<td>Area</td>
<td>0.009</td>
<td>4.37</td>
<td>0.081</td>
</tr>
<tr>
<td>Area squared</td>
<td>-1.2 x 10^{-6}</td>
<td>-2.54</td>
<td>-1.1 x 10^{-5}</td>
</tr>
<tr>
<td>Education</td>
<td>0.158</td>
<td>3.04</td>
<td>1.861</td>
</tr>
<tr>
<td>Age</td>
<td>-0.008</td>
<td>-0.75</td>
<td>-0.090</td>
</tr>
<tr>
<td>Credit constraint</td>
<td>-0.560</td>
<td>-1.88</td>
<td>-22.079</td>
</tr>
<tr>
<td>Public information source</td>
<td>-0.682</td>
<td>-2.26</td>
<td>12.112</td>
</tr>
<tr>
<td>Private information source</td>
<td>-0.725</td>
<td>-2.15</td>
<td>29.000</td>
</tr>
<tr>
<td>Time that farmer knows Bt</td>
<td>0.019</td>
<td>1.50</td>
<td>0.574</td>
</tr>
<tr>
<td>Northern Chaco</td>
<td>-1.177</td>
<td>-4.01</td>
<td>20.025</td>
</tr>
<tr>
<td>Insecticide cost</td>
<td>0.452</td>
<td>1.72</td>
<td>13.664</td>
</tr>
<tr>
<td>High soil quality</td>
<td>-0.005</td>
<td>-2.16</td>
<td>-0.005</td>
</tr>
<tr>
<td>Log-likelihood</td>
<td>-102.790</td>
<td>-146.278</td>
<td>0.485</td>
</tr>
<tr>
<td>Pseudo R^2</td>
<td>0.485</td>
<td>0.491</td>
<td>0.154</td>
</tr>
</tbody>
</table>

---

*a* Also those farmers who used Bt only in 1999/00 were included in the Bt knowledge model.

*b* The coefficients from the WTP model can directly be interpreted as marginal effects.

*c* This is the R^2 from OLS regression with the White estimator.
Figure 1. Estimated percentage of farmers adopting Bt cotton at different price levels

Figure 2. Estimated demand curves for Bt cotton and profit function of seed company