Genetically Modified Crops, Corporate Pricing Strategies, and Farmers' Adoption: The Case of Bt Cotton in Argentina

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This article analyzes adoption and impacts of Bt cotton in Argentina against the background of monopoly pricing. Based on 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 is less than half the actual technology price. A lower price would not only increase benefits for growers, but could also multiply company profits, thus, resulting in a Pareto improvement. Implications of the sub-optimal pricing strategy are discussed.

Key words: biotechnology, contingent valuation, monopoly pricing, willingness to pay.

Recently, genetically-modified (GM) crops have brought about important changes in the global market for agricultural technologies, especially seeds. Prospects of high economic returns and tightened intellectual property rights (IPRs) have provided new incentives for the private sector to invest in crop improvement and extend its business to nontraditional markets. The increasingly proprietary nature of seed technologies has implications for farmers' adoption and benefit distribution. Private innovators, endowed with a patent on a technology, will attempt to capture the gains from their innovation through monopoly pricing (Moschini and Lapan). Recent studies have looked into the partitioning of welfare created by GM crops among agricultural producers, consumers, and innovating input firms (e.g., Moschini, Lapan, and Sobolevsky; Falck-Zepeda, Traxler, and Nelson). In these studies, however, the market price of the technology is not questioned; it is assumed to be fixed at its current level.

Given the rising consolidation in seed markets and the great degree of uncertainty related to the economics of GM crops, the analysis of pricing strategies themselves and their implications for farmers and companies should also be of interest. A monopoly price, as compared to a competitive one, will lower the rate of diffusion and the surplus attributable to 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. This article analyzes empirically the corporate pricing strategy for Bt cotton in Argentina and its impact on farmers' adoption behavior and monopoly profits. Our analysis is based on a representative survey of 299 cotton farms, including adopters and nonadopters of Bt technology, that was carried out in Argentina in 2001.

Bt cotton is a GM crop into which a gene of the soil bacterium *Bacillus thuringiensis* has been transferred to make it resistant to major insect pests. It was developed by Monsanto and, as one of the first GM crop technologies, it became commercially available in the mid 1990s. Since then, the technology has spread rapidly in the United States, 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

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the local company Ciagro. Unlike other countries, however, in Argentina the diffusion of Bt cotton has been rather slow uptil 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.

The most important precondition for widespread adoption of a new technology is its profitability for farmers. We 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 (Genética Mandiyú, personal communication).

Since farmers' responses to changes in the technology price cannot be observed from market data, we use the contingent valuation (CV) method to estimate the willingness to pay (WTP) and construct a demand curve for Bt cotton. A similar approach was also used by Hubbell, Marra, and Carlson in the United States. However, while discussing public sector policy options to achieve certain desirable levels of adoption, they did not analyze corporate pricing strategies. We extend their approach by explicitly questioning the observed monopoly price. Our hypothesis is that the high price of Bt cotton in Argentina not only constitutes an important adoption constraint for farmers, but that a lower price would also lead to higher company profits, thus, resulting in a Pareto improvement, at least on that market. To test this hypothesis, we construct a company-profit function and establish profit-maximizing prices, also considering market segmentation in terms of different farm sizes. Moreover, we examine linkages between the monopoly price level and incentives for IPR infringement. The findings will help to better understand farmers' behavior with respect to GM crop adoption. Furthermore, they might induce a reconsideration of corporate pricing strategies.

The article 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 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 questioned farmers decided not to adopt Bt cotton at the observed market price of $103 per hectare. Combining the revealed and stated preference information from nonadopters provides us with data that are similar to those obtained in a double-bounded CV survey.[1] Moreover, including the revealed preference data from 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 also used the methodology to estimate farmers' WTP for Bt cotton in the United States.

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

$$(1) \qquad U(1, \bar{y}_1 - P; \mathbf{x}) \geq U(0, \bar{y}_0; \mathbf{x})$$

where 1 indicates the Bt technology and 0 the conventional alternative. $\bar{y}_1$ and $\bar{y}_0$ are expected profits from Bt (net of extra technology cost) and conventional cotton, respectively,

[1] Hanemann, Loomis, and Kanninen show that the double-bounded approach is statistically more efficient than the single-bounded approach.

and P is the price of the technology. $\mathbf{x}$ 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

$$(2) \qquad V(1, \bar{y}_1 - P; \mathbf{x}) + \varepsilon_1 \geq V(0, \bar{y}_0; \mathbf{x}) + \varepsilon_0$$

where $V(\cdot)$ is the deterministic part of the utility function, and ε_1 and ε_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

$$(3) \qquad V_i = \beta_i' \mathbf{x} + \alpha(\bar{y}_i - \delta_{i1} P)$$

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

$$(4) \qquad \beta' \mathbf{x} + \alpha(\Delta \bar{y} - P) \geq \varepsilon$$

where $\beta' \mathbf{x} = \beta_1' \mathbf{x} - \beta_0' \mathbf{x}, \Delta \bar{y} = \bar{y}_1 - \bar{y}_0$, and $\varepsilon = \varepsilon_0 - \varepsilon_1$. Unfortunately, we cannot observe expected changes in profit caused by the technology. However, we suppose that this variable can be explained by other farm and household characteristics, so that $\Delta \bar{y}$ is implicitly included in the vector $\mathbf{x}$. In our WTP context, α takes a value of one, as V is measured in monetary units. Assuming that ε is distributed $N(0, \sigma^2)$, the decision to adopt Bt cotton at price P can be expressed in probability form as

$$(5) \qquad \text{Prob}(WTP \geq P) = \text{Prob}[\varepsilon \leq \beta' \mathbf{x} - P] = \Phi\left(\frac{\beta' \mathbf{x} - P}{\sigma}\right) = 1 - \Phi\left(\frac{P - \beta' \mathbf{x}}{\sigma}\right).$$

In a single-bounded approach, equation (5) could be used to estimate the WTP of nonadopters 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

$$(6) \qquad \begin{aligned} \text{Prob}(yes) &= \text{Prob}(WTP \geq P^M) \\ \text{Prob}(no/yes) &= \text{Prob}(WTP \leq P^M) - \text{Prob}(WTP \leq P^*) \\ \text{Prob}(no/no) &= \text{Prob}(WTP \leq P^*). \end{aligned}$$

Correspondingly, the log-likelihood function for this WTP model is

$$(7) \qquad \begin{aligned} \ln L = \sum_{i=1}^{n} & I^Y \ln\left[1 - \Phi\left(\frac{P^M - \beta' \mathbf{x}}{\sigma}\right)\right] \\ & + I^{NY} \ln\left[\Phi\left(\frac{P^M - \beta' \mathbf{x}}{\sigma}\right) - \Phi\left(\frac{P^* - \beta' \mathbf{x}}{\sigma}\right)\right] \\ & + I^{NN} \ln\left[\Phi\left(\frac{P^* - \beta' \mathbf{x}}{\sigma}\right)\right] \end{aligned}$$

where the I symbols denote binary indicator variables for the three response groups (i subscripts suppressed).[2] Unlike a regular probit model, which yields parameter estimates only up to a factor of proportionality (i.e., β/σ), the coding of our likelihood function allows one to estimate β directly. The advantage is that the estimated coefficients can be interpreted as the marginal effects of the $\mathbf{x}$ variables on WTP in dollar terms. Since, in a probit, the implied parameter on the price variable is $1/\sigma$, it takes a value of one in our specification. Thus, the mean WTP is calculated as $\beta' \mathbf{x}$.

Using these results, we can predict the share of farmers likely to adopt Bt cotton (*ASHARE*) at different price levels. In order to construct a demand curve, though, we need additional 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 household, farm,

[2] An implicit assumption behind combining adopters and nonadopters 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 nonadopters.

and contextual characteristics and the price of the technology ($P = P^M$ or P^*) so that

$$(8) \qquad BTPROP = \gamma'\mathbf{x} + \eta P + u$$

where u is a random error term with mean zero. Although, this area proportion model could be estimated using ordinary least squares (OLS), 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 nonrandom 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 equation (8).[3] *BTPROP* is not censored at one, because respondents could state the contingent Bt area to be larger than their present total cotton area. However, Hubbell, Marra, and Carlson found in their study that there was significantly more variance in the responses of contingent adopters than of current adopters. Therefore, we use an iterated generalized least squares (GLS) estimator with heteroskedasticity correction across groups, which assumes that the variance matrix of the disturbance terms is

$$\boldsymbol{\Omega} = \begin{bmatrix} \sigma_1^2\mathbf{I} & 0 \\ 0 & \sigma_2^2\mathbf{I} \end{bmatrix}.$$

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

$$(9) \qquad Q_D(P) = ASHARE(P) \times BTPROP(P) \times TOTCOT_t$$

where $TOTCOT_t$ is the total cotton area in the country observed in the reference year t. Although $TOTCOT_t$ is a constant, we do not assume that the total crop area is completely independent of P. As *BTPROP* can be bigger than one, Q_D can be bigger than $TOTCOT_t$, 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.

[3] Since our WTP model estimates β rather than β/σ, we divide all parameters by σ for calculation of the Mills ratio.

So far, we have only considered farmers' demand for Bt cotton, assuming that the price would be set exogenously. However, from the innovator's point of view, the technology price is endogenous, because the patent imparts monopoly power. The innovator's profit π as a function of the technology price is simply

$$(10) \qquad \pi(P) = (P - C) \times Q_D(P)$$

where C is the marginal cost of producing Bt seeds, which is assumed to remain constant, independent of volume produced. Differentiating equation (10) and solving for the profit-maximizing price results in

$$(11) \qquad P^{\text{Max}} = \frac{C}{1 + (1/\eta)}$$

where η is the price elasticity of demand, which is expected to be negative. Obviously, the higher the price responsiveness of farmers, the lower is the optimal monopoly price for Bt seeds, a relationship we solve numerically in a later section.

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 nonadopters 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 of 89 adopters (about 60% of all adopters in the country) and 210 nonadopters. A check with official statistics (SAGPYA) and census data showed that the sub-sample of nonadopters 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

Table 1. Selected Farm and Cotton Cultivation Characteristics in 2000–2001

Characteristic	Nonadopters: Minifundio ($n = 126$)	Nonadopters: Small ($n = 47$)	Nonadopters: Medium and Large ($n = 37$)	Bt Adopters ($n = 89$)[a]
	Mean (Standard Deviation)			
Total cultivated area (ha)	10.0	42.7	1,061.9	1,183.7
	(10.4)	(48.1)	(3,041.4)	(1,400.0)
Cotton area (ha)	4.6	19.7	482.4	463.6
	(2.2)	(5.6)	(1,451.7)	(544.0)
Seed cotton yield (kg/ha)	1,020.0	1,239.0	1,516.8	1,591.8[b]
	(421.8)	(475.0)	(432.6)	(483.1)
No. of insecticide applications	2.9	3.0	4.5	5.0[b]
	(1.9)	(2.1)	(1.5)	(1.8)
Total cost of purchased inputs ($/ha)	31.9	52.8	81.9	110.2[b]
	(23.1)	(23.7)	(29.7)	(32.9)
Mechanized harvest (%)	1.6	48.9	81.1	97.8

[a] 73 adopters in 2000–2001 and 29 in 1999–2000.
[b] These figures refer to the conventional cotton plots of Bt adopters.

Bt and conventional plots. Furthermore, the questionnaire covered aspects of farmers' perceptions about Bt technology. Table 1 shows different characteristics of users and nonusers. In order to account for heterogeneity in the Argentine cotton sector, we subdivided the nonadopters 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 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, Bt adopters are fairly representative of the group of medium and large farms. Indeed, none of them belongs to the group of minifundio and small producers.

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 gossipiella*), 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, Argentine seed law allows farmers to reproduce their cotton seeds for one season before they have to buy fresh, certified material.[4] 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

[4] In our survey, 63% of the farmers stated that they used certified, conventional seeds in 1999–2000, while in 2000–01, the rate was 59%. The rest was using uncertified material, including from their own harvested crop, but also seeds reproduced by other farmers, which are typically traded by the ginning factories. Such transactions are actually not allowed, but are difficult to monitor, because even farm-saved seeds are channeled through these factories for delinting. The use of uncertified material is common among both small and large farms.

Table 2. The Diffusion of Bt Cotton

	1998–99	1999–2000	2000–01	2001–02
Total national cotton area (ha)	750,930	331,890	409,950	169,000
Bt cotton area (ha)	5,500	12,000	22,000	9,000
Bt in percent of total national area	0.7	3.6	5.4	5.3
Average Bt area per adopter (ha)[a]	93.6	109.6	153.8	118.4
Bt in percent of total cotton area on farm[a]	15.7	34.9	50.8	41.8

[a]These figures are results from the farm survey.
Sources: ASA, Pellegrino, industry estimates, and farm survey.

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 decisions. The cotton area in 2001–02 was the lowest in the last 30 years. However, local experts reckon that, even at low world market prices, the area will again reach a level of around 400,000 hectares in the medium run.

Table 2 shows only 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. This is an infringement of the purchase contracts, but so far there is no precedence of legal prosecution. Discussions with farmers and input providers, however, revealed that there is also a sizable black market for reproduced Bt seeds, so that there are also many unofficial Bt users, who never signed a contract with Genética Mandiyú. In our sampling framework, only official users were defined as Bt adopters.

Unlike other countries, where grower satisfaction with Bt cotton is generally high, in Argentina the dropout rate of users is significant. In our sample, only about half of the farmers who used Bt technology during the last three years decided to also use it in the following year. How far disadoption of official Bt seeds is driven by own seed reproduction, is difficult to tell based on the data available. There are farmers who had stopped using Bt in one season, but adopted again after one or two years break.

Farm-Level Effects of Bt Cotton

To analyze the farm-level effects of Bt cotton in Argentina, we compare cost of production and 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 allows us to examine differences between the two alternatives, holding management and equipment complements constant. Average farm-level differences ($\bar{D}$) in cost of production and gross margins are calculated as

$$\bar{D} = \frac{1}{n}\sum_{i=1}^{n}(Bt_i - Conv_i)$$

where Bt_i and $Conv_i$ are per-hectare expenditures (or revenues) on farm i's Bt and conventional plots, respectively, and n is the number of adopters in a particular season. 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,

Table 3. Effects of Bt Cotton on Gross Margins (in US$/ha)

	1999–2000			2000–01		
	Bt ($n = 24$)	Conv. ($n = 24$)	Difference ($n = 24$)	Bt ($n = 61$)	Conv. ($n = 61$)	Difference ($n = 61$)
	Mean (Standard Deviation)					
Seed cotton yield (kg/ha)	2,062.50	1,558.33	504.17[a]	2,182.62	1,625.41	557.21[a]
	(564.00)	(316.11)	(86.91)	(576.63)	(468.74)	(64.46)
Gross revenue	537.94	402.04	135.90[a]	419.31	311.99	107.33[a]
	(193.82)	(120.95)	(23.98)	(151.37)	(125.34)	(12.57)
Variable cost						
Seed	104.90	14.64	90.26[a]	102.22	18.17	84.04[a]
	(11.64)	(7.50)	(3.19)	(11.22)	(8.80)	(1.78)
Insecticides	17.07	32.43	−15.35[a]	22.83	42.33	−19.50[a]
	(12.10)	(10.72)	(2.20)	(12.88)	(21.36)	(2.18)
Other inputs	53.05	52.42	0.63	59.65	52.38	7.27
	(19.32)	(18.58)	(1.75)	(54.32)	(14.33)	(6.84)
Own machinery	96.82	90.03	6.79[a]	107.25	99.65	7.59[a]
	(46.31)	(37.71)	(3.38)	(56.44)	(49.79)	(2.00)
Hired labor & custom	59.29	52.70	6.59	73.72	61.31	12.41[a]
operations	(77.41)	(60.84)	(4.11)	(72.06)	(53.35)	(3.78)
Commercialization	32.48	24.54	7.94[a]	34.38	25.60	8.78[a]
	(8.88)	(4.98)	(1.37)	(9.08)	(7.38)	(1.02)
Total variable cost	363.62	266.76	96.86[a]	400.04	299.45	100.59[a]
	(67.45)	(49.60)	(7.11)	(88.29)	(70.35)	(9.53)
Gross margin	174.32	135.28	39.04[a]	19.27	12.53	6.74
	(154.58)	(104.19)	(18.70)	(132.18)	(83.44)	(12.24)

[a]Significantly different from zero at 5% level (one-sided t-test).

which might bias the analysis, were accounted for by excluding farmers who grew Bt and conventional cotton on plots with significantly different soil qualities. 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 3.

As expected, Bt technology reduces the expenditure on insecticides. In 1999–2000, 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. Machinery and labor costs are somewhat higher on Bt plots. Although there is a slight decrease in operating expenses for pesticide applications, this is more than offset 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 expenditure for the bundle of purchased inputs.[5] Altogether, average gross margins are higher with Bt technology in 1999–2000 and 2000–01.[6] There is a high variation across farms, however, and for 2000–01, the difference is not statistically significant from zero. Also, mean values hide the fact that, in both seasons, around 40% of the Bt adopters actually experienced a decrease in gross margins. Unsurprisingly, these are largely those farmers who dropped out the following year.

Compared with other countries where Bt cotton is grown, farm-level benefits in Argentina are rather small. In the US, average per-hectare benefits ranged between $50 and $80 in recent years (Gianessi et al.; Barnett and Gibson). For China, Pray et al. reported gains of over $400 for the 1999–2001 period, and in Mexico, Traxler et al. found average net benefits of $295 per hectare for 1997 and 1998. While, in these other countries,

[5] For small farms, Bt cotton seeds would almost triple, and for minifundios even quadruple, the total cost of purchased inputs (see table 1).

[6] Elena carried out a study for Argentina based on data collected by Monsanto for the 1999–2000 season. Her results are similar to ours for the same season.

the major advantage of Bt technology is a drastic reduction in pesticide expenditures, in Argentina the main effect is an increase in effective yields. The increase in total production cost associated with Bt intensifies the financial risk that farmers face. Net benefits mainly depend on extra revenues, which are also a function of cotton prices. A downward trend in world market prices, as currently observed, therefore lessens the technology's comparative advantage. Although yield increases in Argentina were similar in both growing seasons, the absolute gain in gross margins was much lower in 2000–01 because of the decline in cotton prices. Indeed, the difference in gross margins in 2000–01 would have been significant at the 5% level, had cotton prices remained unchanged. The effects of output price variation on profitability of Bt 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, 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 performance to a large extent. Splitting the seed price by two and adding the cost associated with seed saving and delinting, we calculated additional crop budgets. It is interesting to note that, under these assumptions, Bt technology would still increase the total per-hectare cost of production. Yet, net benefits would be considerably larger. Had farmers bought Bt cotton in 1999–2000 and used farm-saved seeds in 2000–01, average gains in gross margins would have been around $85 and $52,9 respectively.

Willingness to Pay for Bt Cotton

Since our farm survey was carried out in 2001, we take the 2000–01 cotton growing season as the reference for the WTP analysis. That is, farmers who used Bt cotton in this particular season were defined as adopters. Sixteen farmers used the technology in 1999–2000 but not in 2000–01. On the one hand, including them in the group of nonadopters is slightly incorrect, on account of the stratified sampling procedure. On the other hand, as was shown above, disadoption is correlated with previous-year experience. Disadopting farmers are much better informed about Bt performance than their counterparts who never used the technology. Indeed, Marra, Hubbell, and Carlson found that—when available—previous own-farm experience is the most important factor determining adoption of Bt cotton in the US. Against this background, not using the information from disadopters might lead to a greater bias than including them in the analysis. This holds true especially for Argentina, where disadoption is a common phenomenon. Therefore, for the CV questions, those farmers were treated the same as other nonadopters.

Nonadopting farmers were asked whether they would have used the technology in 2000–01 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.[7] The average competitive price of conventional, certified seeds is $25, 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.

A significant proportion of farmers were not familiar with Bt cotton (64% of the nonadopters). 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 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 have used 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 4. Observations with missing variables were left out

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[7] 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.

Table 4. Explanatory Variables and Summary Statistics

	Nonadopters ($n = 219$)		Adopters ($n = 70$)	
	Mean	SD	Mean	SD
Area (cultivable area owned in ha)	92.00	396.58	725.27	1155.47
Education (farmer's number of years in school)	5.64	3.00	10.00	3.90
Age (farmer's age in years)	49.21	11.53	47.10	10.67
Credit constraint (dummy)	0.86	0.35	0.49	0.50
Public information source (dummy for major source)	0.51	0.50	0.10	0.30
Private information source (dummy for major source)	0.26	0.44	0.79	0.41
Time that farmer knows Bt (number of years)	0.84	1.22	2.94	0.96
Northern Chaco (dummy for farms located in northern Chaco)	0.26	0.44	0.01	0.12
Insecticide cost (in $/ha)[a]	11.45	9.37	29.18	13.19
High soil quality (dummy for above average soil quality)[b]	0.27	0.45	0.16	0.37

[a]This is a 1999–2000–2000–01 average. For adopters, the figure refers to their conventional plots. Only the cost of insecticides used against Bt target pests is considered.
[b]For farmers with more than one cotton plot, an area-weighted soil quality index was used to construct this variable.

of the analyses. Accordingly, the sample for the WTP model consists of 219 nonadopters 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 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 and 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 insecticide cost variable 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 1999–2000 and 2000–01 as instruments. The test statistics are negative for all three models: for the Bt knowledge model $\chi^2_{(8)} = -2.69$, for the WTP model $\chi^2_{(9)} = -7.75$, and for the area proportion model $\chi^2_{(11)} = -6.89$. Based on these values, we reject the hypothesis that insecticide cost is correlated with the error terms in all cases. The estimation results are presented in table 5.

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 the public extension service has not yet been involved in dissemination efforts. Often, extension agents themselves have inadequate knowledge about details of the technology. Those farmers who know Bt cotton often learned about it from neighbors, whereas farmers in northern Chaco appear to be at an information disadvantage. These results are consistent with Marra, Hubbell, and Carlson, who demonstrated the influence of different sources and quality of information on farmers' technology perceptions and adoption decisions.

The WTP model also shows a significantly positive effect of cultivable area owned. On average, each additional hectare increases the WTP for Bt cotton seeds by 3 cents. Although the technology as such is totally divisible, conclusion of the purchase contracts and

Table 5. Model Results

Variables	Bt Knowledge Model ($n = 289$) Coefficient	Bt Knowledge Model ($n = 289$) t-statistic	WTP Model ($n = 289$) Coefficient[a]	WTP Model ($n = 289$) t-statistic	Area Proportion Model ($n = 155$) Coefficient	Area Proportion Model ($n = 155$) t-statistic
Constant	−0.205	−0.24	18.340	0.93	0.805	2.67
Area	0.009	4.37	0.033	2.43	-8.1×10^{-6}	−0.26
Area squared	-1.2×10^{-6}	−2.54	-4.8×10^{-6}	−2.22		
Education	0.158	3.04	2.361	2.30	0.023	2.51
Age	−0.008	−0.75	0.000	0.00	0.001	0.29
Credit constraint	−0.560	−1.88	−20.140	−3.04	0.015	0.21
Public information source	−0.682	−2.26	9.391	1.26	−0.000	−0.00
Private information source	−0.725	−2.15	22.873	3.00	−0.007	−0.07
Time that farmer knows Bt			9.946	3.95	−0.004	−0.13
Northern Chaco	−1.177	−4.01	18.425	2.49	−0.121	−0.69
Insecticide cost	0.019	1.50	0.810	2.90	0.006	2.67
High soil quality	0.452	1.72	8.884	1.31	0.109	1.29
Bt price bid					−0.006	−2.75
Mills ratio					−0.066	−2.68
Log-likelihood	−102.790		−178.199		−122.280	
Pseudo R^2	0.485		0.546			

[a]The coefficients from the WTP model can directly be interpreted as marginal effects.

compliance with these contracts have to be seen as fixed 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 over the range of farm sizes.

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 is 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).[8] These findings indicate that appropriate information campaigns could definitely promote the process of technology diffusion.

The influence of a credit constraint on WTP is 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. That risk attitudes can play a large role in determining technology adoption was theoretically shown by Just and Zilberman. This holds true, in particular, when the startup cost is high, as is the case for Bt seeds in Argentina. 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 81 cents. That this value is lower than 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 at the beginning of the crop cycle, before pest pressure is known, whereas chemical insecticides can be purchased at a later stage according to actual needs.

Based on these estimates, we calculated the mean WTP, inserting average values of the explanatory variables. Given the stratified

[8] 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 5. 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.

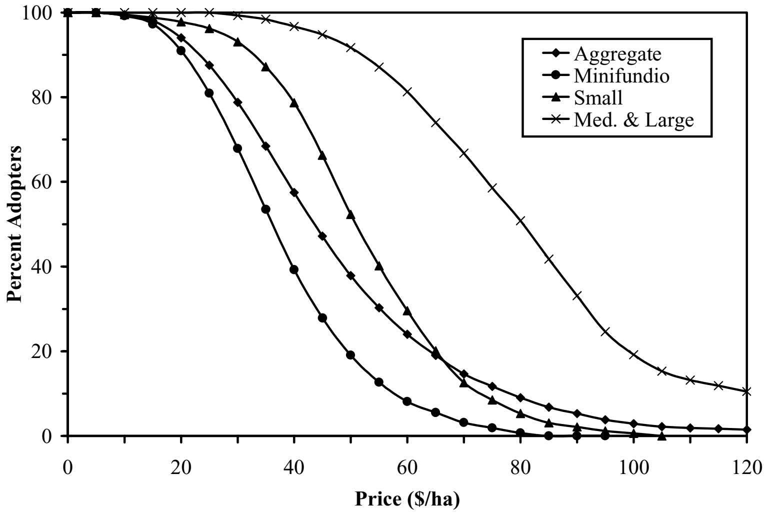

Figure 1. Estimated percentage of farmers adopting Bt cotton at different price levels

sampling procedure and the inclusion of disadopters (which led to an oversampling of larger farms among the 2000–01 nonadopters), the calculations were done separately for adopters and the three farm-size groups of nonadopters. The aggregate was then derived by using the sub-samples' weight in the overall population of cotton producers. The mean WTP for Bt cotton in Argentina is US $48, less than half the actual price of $103. Subtracting the seed cost, the WTP is equivalent to a technology premium of around $23 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 difference is probably due to a series of factors, including environmental conditions and farmers' general mentality with respect to own seed reproduction. Additionally, the United States cotton growers receive substantial output price subsidies, which promotes higher input intensities and increases the technology's value at the farm-level. We are not aware of WTP studies for Bt cotton in other countries that could further enhance the overall picture.

As the coefficient for area in the WTP model has already suggested, larger farmers in Argentina are willing to pay more for Bt cotton than smaller ones. The mean WTP for minifundios is $38, for small farms it is $52, and for medium and large farms (including adopters) it is $83. Interestingly, these values are very 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 minifundio and small farms, the adoption curves are fairly steep until a price level of about $60–65, 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 5 also shows the results of the area proportion model described in equation (8), which was estimated using iterated GLS. Many parameters are not statistically significant. Yet, the coefficient of the price bid is significant and negative, indicating that not only would more farmers adopt at lower technology prices but that adopters would also plant a higher proportion of their area to Bt cotton. Education and insecticide cost have a positive influence on the Bt proportion, which could have been expected given the earlier results. The *t*-statistic for the coefficient of the Mills ratio confirms that nonrandom selection bias would have been an issue in a standard OLS regression. Also, the estimated variance of the disturbance term is significantly lower for current than for contingent adopters, so that our model with heteroskedasticity correction produces efficient estimates.

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 population weights into account. By applying the formula in

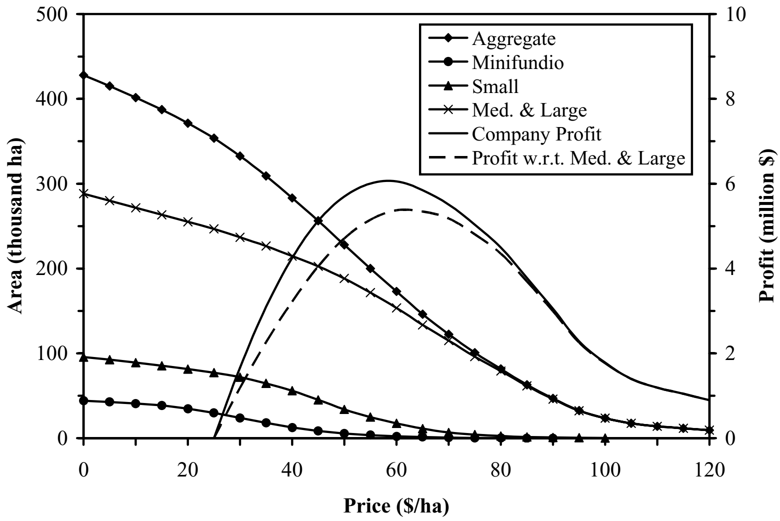

Figure 2. Estimated demand curves for Bt cotton and profit functions of seed company

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, price responsiveness of the Bt area is high: at the current market price, the aggregate demand curve has a point elasticity of –4.8, and at a price of $95, the elasticity is –13.1. 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:[9] 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 with respect to aggregate demand is also shown in figure 2 (the continuous line).

At the current price, company profit is around $1.7 million. The profit increases steeply with decreasing prices until it reaches its maximum at a price level of $58. At this price, we predict a Bt cotton area of 184,000 hectares and a company profit of $6.1 million.[10] These findings clearly confirm our premise that the current pricing strategy is sub-optimal, at least for this market. Although, the absolute numbers would change, this general statement also holds if the total national cotton area was smaller than in 2000–01. For illustration, we carried out the same computations but assuming the cotton area observed 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 again be around $58 per hectare.

Of course, our assumption of constant marginal costs for the production and

[9] In the late 1990s, Genética Mandiyú established new production and processing facilities with an annual capacity of up to one million bags of Bt seeds.

[10] Figures 1 and 2 reveal that at a price of $58 adoption among minifundio and small farms would still be much lower than among larger farms, reinforcing relative income inequality. However, in absolute terms, nonadopters would not be worse off, because Argentina is a small and open cotton-producing economy, so that technological progress has no effect on the output price.

dissemination of Bt seeds could be questioned. When more and more farmers, including smallholders, adopt the technology, transaction costs associated with sales and monitoring of contract compliance will probably rise progressively. So Genética Mandiyú might see large-scale producers, whose WTP is higher anyway, as the main target group. In order to test whether this explains the observed monopoly price, we recalculate the profit function with respect to the demand curve of medium and large-scale farmers only. This alternative function is also shown in figure 2 (the dotted line). The profit-maximizing price would rise to \$62, which is still well below the current market price. In fact, the difference to the initial maximum of \$58 is small, which shows that—in this particular context—only targeting larger producers would hardly change the optimal pricing strategy.[11]

Another interesting question is how the official market price of the technology influences the extent of illegal Bt plantings. Assuming risk neutrality, the decision to switch from illegal to legal seeds will only be made if $\bar{y}_L - P_L \geq \bar{y}_{IL} - P_{IL} - \varphi F$, where $\bar{y}_L$ and $\bar{y}_{IL}$ are the expected returns of using legal and illegal Bt seeds, respectively, and P_L and P_{IL} are the corresponding seed prices. φ is the probability that illegal use will be detected, and F is the resulting fine. Rearranging, we obtain $\Delta P \leq \Delta \bar{y} + \varphi F$, where $\Delta P = P_L - P_{IL}$ and $\Delta \bar{y} = \bar{y}_L - \bar{y}_{IL}$. Hence, *ceteris paribus*, a smaller ΔP through declining official prices would increase demand for legal seeds and reduce the extent of illegal plantings.

The risk of legal action depends on the degree of law enforcement. While own reproduction of Bt seeds implies an infringement of the private contracts with Genética Mandiyú, black-market transactions also violate the national seed law. So far, enforcement of both has been rather lax in Argentina. Nonetheless, the perceived risk of cheating is definitely greater than zero. In our survey, 27% of the farmers who knew Bt cotton believed that the seed contracts could easily result in legal problems, while 48% of the respondents were unsure. This suggests that many farmers would be willing to pay a legality premium $\Delta P > 0$, even if $\Delta \bar{y}$ is small, a finding which is consistent with our price-elastic demand curves. Black-market seeds are currently sold at \$35–40 per hectare. Given that risk attitudes differ, the predicted official adoption of 184,000 hectares at a price of \$58 presumably already includes quite a few of those farmers who choose to grow illegal seeds at the current price of \$103.

Another option to reduce the size of the black market would certainly be to increase the risk of cheating. This, however, would be associated with higher monitoring and enforcement costs, and cannot be controlled entirely by the innovating company. Giannakas showed analytically that complete deterrence of IPR infringement is not always economically optimal for developing-country governments.

Discussion and Conclusions

This article has analyzed the impact of the corporate pricing policy for Bt cotton in Argentina on technology demand, farm-level benefits, and company profits. Although the limited flow of information was also identified as an adoption constraint, the main hurdle for wider dissemination 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 farmers' average willingness to pay for Bt cotton is less than half the actual market price. Accordingly, the demand curve is very elastic at higher price levels. Yet, the analysis also revealed that the current price is almost 80% higher than the level that would maximize the monopolist's profits. At the optimal price level, company profits could be about 3.6 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 generates unfavorable publicity for biotechnology, because it gives support to opponents 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 can be seen as a direct outcome of the corporate pricing strategy. Although cheap, illegal seeds can augment benefits for cotton growers in the short term, the private sector's inability to generate profits will

[11] Omitting Bt disadopters in the analysis would result in a profit-maximizing price of \$64, when the company targets all cotton growers, and of \$69, when only medium and large farms were taken into account.

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. While lower official prices would probably not completely eliminate the problem of illegal plantings, they would reduce the size of the black market substantially.

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 ignore the fact that cotton-growing conditions in Argentina are very different from those in the United States. Argentina is a low-cost cotton producing country, and farmers do not receive output price subsidies. Hence, the value of Bt cotton is on average lower for Argentine farmers than for their US counterparts. The logical consequence should be differential pricing.

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 based on factors outside 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 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 United States (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 purpose of protecting US farmers, because the growing size of the black market for Bt seeds in Argentina can hardly be in their best interest. A more detailed analysis of the forces behind pricing strategies in global GM seed markets is beyond the scope of this article. It would, however, be an interesting topic for future research.

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