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Impact of Bt Cotton in China

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Summary. — A sample of 283 cotton farmers in Northern China was surveyed in December 1999. Farmers that used cotton engineered to produce the Bacillus thuringiensis (Bt) toxin substantially reduced the use of pesticide without reducing the output/ha or quality of cotton. This resulted in substantial economic benefits for small farmers. Consumers did not benefit directly. Farmers obtained the major share of benefits and because of weak intellectual property rights very little went back to government research institutes or foreign firms that developed these varieties. Farmers using Bt cotton reported fewer pesticide poisonings than those using conventional cotton. © 2001 Elsevier Science Ltd. All rights reserved.

Key words — biotechnology, cotton, Asia, China, agriculture, economics

1. INTRODUCTION

Genetically engineered (GE) plants [1] are the center of an increasingly rancorous debate about the value of agricultural biotechnology. The champions of biotechnology such as Monsanto and the Biotechnology Industry Organization see agricultural biotechnology as a tool to help solve problems of hunger and excessive pesticide use. The critics of biotechnology such as Altieri and Rosset (2000) say that plant biotechnology is not needed, will be bad for consumers' health, will impoverish small farmers, will fatten the profits of companies such as Monsanto, will increase pesticide use, and reduce biodiversity.

This debate is particularly important for developing countries, most of which have not yet decided whether to allow the use of GE plants or not. GE cotton, soybean, and corn varieties have increased yields and profits and decreased pesticide use of farmers in the United States (Gianessi & Carpenter, 1999, Fernandez-Cornejo & Klotz-Ingram, 1998, Fernandez-Cornejo & Klotz-Ingram Jans, 1999). Few *ex post* studies of farm-level impact of biotechnology so far have been published about countries outside the United States and to our knowledge none have been conducted in developing countries. [2] This study starts to remedy that problem by providing evidence on the farm level impact of biotechnology with a case study of GE cotton production in China. It attempts to measure the economic, income distribution, environmental and health impacts of biotechnology in a developing country where agriculture is dominated by small farmers.

This paper is divided into five more sections and a concluding section. Part two describes

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the development and spread of genetically engineered cotton in China. Part three contains the methodology and description of the sample of farmers. Part four examines the size of the economic benefits. Part five looks at the distribution between farmers and other groups in society as well as between different groups of farmers. Part six reports the environmental and safety data. The conclusion revisits the critiques of biotechnology in light of the Chinese data and then looks at some of the policy implications of the study.

2. THE DEVELOPMENT AND SPREAD OF GENETICALLY ENGINEERED COTTON IN CHINA

In 1991 the Biotechnology Research Center of the China Academy of Agricultural Sciences' (CAAS) initiated a major research program to develop cotton varieties that would contain a gene that would produce a *Bacillus thuringiensis* (Bt) [3] toxin which would control cotton bollworm. [4] After 1–1.5 years of the project CAAS developed and patented a new Bt gene. [5] The gene was inserted into commercial cotton varieties using a process developed by Chinese scientists. [6]

The first successful genetically engineered cotton plant was produced in China in 1993. By 1999, 20 new cotton varieties containing the Bt gene had been produced. In 1995 CAAS started testing these varieties in experimental fields regulated by the Ministry of Agriculture. The first Bt varieties were given to farmers for commercial planting on a small scale the next year. In 1997 the Chinese biosafety committee approved four CAAS varieties for commercial use in nine provinces. Farmers planted 10,000 ha of CAAS Bt cotton in nine provinces in 1998. CAAS had difficulty selling more of it in 1998 because the government seed companies, which have regional monopolies on cotton seed sales, were not interested in distributing it. [7] As a result CAAS formed a joint venture to commercialize Bt cotton called Biocentury Transgene Corporation Ltd. The joint venture partners are CAAS, a real estate company based in Shenzen in Southern China, and the Ministry of Science and Technology. Biocentury then contracted with three provincial seed companies to produce and distribute Bt cotton seed in 1999. This greatly increased Bt cotton seed production. CAAS Bt cotton seed was grown on 100–120,000 ha in 1999.

Recently CAAS had a new genetically engineered variety, SGK321, approved. Two pesticidal genes—one which produces the Bt toxin and the other produces a cowpea trypsin inhibitor [8]—were inserted into SGK321 to control bollworm. CAAS believes that it will take bollworms much longer to develop resistance to cotton varieties with two genes than cotton varieties with only the Bt gene.

Monsanto, Calgene, Agracetus, DuPont and others started developing genes for insect and herbicide resistant cotton in the mid-1980s in the United States. They conducted the first field trials of genetically engineered varieties in 1989. Delta and Pineland (DPL), which had the largest share of the US cotton seed market, started negotiating with several companies to have their varieties transformed with insect and herbicide resistance genes in 1988 and 1989. DPL signed nonexclusive agreements with several companies for the introduction of these genes. In 1993 they signed an exclusive agreement with Monsanto to market transgenic cotton internationally except in Australia and India.

DPL began formal research on cotton in China in 1995 in partnership with the CAAS Cotton Research Institute in Henan Province. It tested a number of different US varieties and a number of different Bt genes. In November 1996 Monsanto, DPL and the Singapore Economic Development Authority developed a joint venture with the Hebei provincial seed company to produce and market GE cotton seed through a new company called Ji Dai. After testing a number of different varieties, they decided that the US transgenic variety 33B controlled cotton bollworm, outyielded both GE and conventional varieties, and had good fiber quality. The Chinese biosafety committee approved it for commercial use in Hebei province in 1997. Commercial seed production started that year on 10,000 ha and Ji Dai built a state-of-the-art seed production facility in Shijiazhuang, Hebei in 1997.

Commercial production of 33B started in 1998 in Hebei. In 1999 33B production was still allowed only in Hebei, but it was also being grown in neighboring provinces through farmer to farmer seed distribution and through seed traders. In 1999 Monsanto-DPL (MDP) had two new varieties of Bt cotton approved for Anhui Province. They are setting up a new joint venture with the Anhui Provincial Seed Company to sell seeds there in 2000. In addition at the beginning of 2000 they received

Table 1. *Area of Bt cotton in China—various estimates (1,000s of hectares)*[a,b]

	Estimates of Bt cotton area				Total cotton area
	Hebei	Shandong + 8 prov.	Henan[c]	Industry estimates[d]	
1997	3				4,491
1998	50–55	10			4,459
1999	100–110	120	100	1,000	3,726

[a] *Sources*: Hebei and Shandong + from Monsanto and CAAS interviews Beijing, November 2 and 3, 1999.
[b] Total Area 1997 and 1998 from National Bureau of Statistics (1999). Total area 1999 Foreign Agricultural Service, USDA (2000).
[c] Henan US Embassy estimate Bean (1999).
[d] Agronomists estimated the percentage of cotton land under Bt cotton in provinces of north China. This percentage was applied to USDA's estimates of total area.

permission to sell 33B in Shandong Province for the crop year 2000.

The Cotton Research Institute in Henan also has its own Bt cotton variety development program. Their varieties are spreading in Henan Province. The US Embassy reports (Bean, 1999) that in 1999 Bt cotton covered one fifth of the cotton area of Henan Province. That would cover at least 100,000 ha.

The estimates of area covered with Bt cotton are shown in Table 1. MDP and CAAS provided estimates of the areas covered by their Bt varieties. The US Embassy estimate of Bt cotton for Henan province is found in column 3 (Bean, 1999). In interviews with agronomists from MDP we asked for their estimates of the percentage of area in eastern provinces under Bt varieties of any type. When we apply those percentages to the 1998 (the latest provincial data available) area of cotton in those provinces, the area planted adds up to 1.3 million hectares. Adjusting that figure downward for the reduction in cotton area in 1999 suggests that there could have been as much as a million ha of Bt cotton planted in 1999.

While a million ha may be too high, the companies' estimates are too low because farmers save seed and sell it to their neighbors or seed merchants. For example, all of the 33B in Shandong is from sources other than J. Dai. (see Table 2). Thus, the area under Bt cotton must be between 300,000 ha and one million ha.

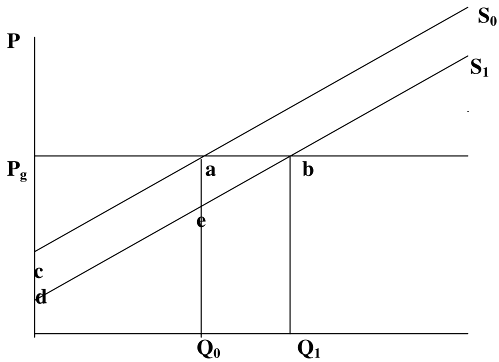
3. METHODOLOGY AND DATA

In order to assess the economic impact of Bt cotton on farmers and consumers the standard consumer producer surplus model (see Alston, Norton, & Pardey, 1995) was used. To assess the division of benefits between farmers and suppliers of biotechnology the Moschini and Lapan (1997) framework was followed. This framework shows that the total benefit to society is not only the consumer and producer surplus, but also includes the profits of companies that supply the new technology. Our model of the cotton market with and without biotechnology is shown in Figure 1. We assume that Bt cotton causes a parallel shift in the cotton supply curve from S_0 to S_1 due to the reduction in cost of production in fields where it is grown. The demand curve facing farmers is perfectly elastic at the government price P_g because in 1999 government bought 72% of the cotton in China at a government determined price (Foreign Agricultural Service, USDA, 2000). [9] To estimate the economic surplus in this model requires an estimate of the supply curve shifter. The supply shifter can be estimated using experimental data or data from farmers. In this study the shifter is estimated

Table 2. *Varieties used by surveyed farmers*[a]

Variety	% Area of surveyed farmers in each province
Shandong province	
Bt cotton	85.6
33B	36.5
GK-12	39.8
SGK321	1.0
Other Bt	8.3
Non-Bt cotton	14.4
Bollworm resistant	2.9
Susceptible to bollworm	11.4
Hebei province	
Bt cotton	100
33B	72.9
SGK321	27.1

[a] *Source*: Survey.



Producer Surplus = abcd ≈ abQ_0 Q_1 = Economic Surplus

Consumer Surplus = 0

Figure 1. *Economic surplus from adoption of Bt cotton 1999.*

using costs and returns data of farmers who did and did not use Bt cotton.

A few studies of the impact of GE plants are starting to be published. So far almost all of studies have been on the United States. Several studies (Gianessi & Carpenter, 1999; Gianessi & Carpenter, 2000; Hyde, Martin, Preckel, & Edwards, 1999; Fernandez-Cornejo & Klotz-Ingram, 1998, Fernandez-Cornejo *et al.*, 1999, Marra, Carlson, & Hubbell, 1998) estimate the impact of GE plants on yields, profits and input use in the US. The USDA studies (Fernandez-Cornejo & Klotz-Ingram, 1998, Fernandez-Cornejo *et al.*, 1999), which are based on the largest sample of farmers (2,000+), looked at major corn, soybean and cotton growing areas of the United States. They found that farmers using herbicide-tolerant corn reduced acetimide herbicides. Herbicide-tolerant soybeans had a small yield increase, reduced use of other herbicides and increased the use of glyphosate (Round-Up). Herbicide-tolerant cotton increased farmer's yields and profits. Bt cotton increased yields and profits and reduced pesticide use. The impact of Bt corn has been harder to measure. Some studies find increased yields and returns to farmers (Gianessi & Carpenter, 1999) and while others do not (Hyde *et al.*, 1999).

Two studies have looked at the distribution of benefits between farmers, the input supply industry, and the rest of the world. Falck-Zepeda, Traxler, Nelson, and McBride (1999) calculated how much of the benefits from GE cotton and soybeans in the United States went to biotech and seed companies and how much went to farmers. They find that most of the benefits go to farmers and consumers but that Monsanto and Delta and Pineland also got substantial benefits. Moschini, Lapan, and Sobolevsky (1999) argue that Monsanto captured most of the benefits from the spread of genetically engineered soybeans and that much less has gone to farmers.

In China data on costs and returns of Bt cotton and conventional cotton were not available from the government or industry. Thus, a farm-level survey was necessary. This study was conducted jointly by the Center for Chinese Agricultural Policy, Beijing (CCAP) of CAAS, Beijing, and the Department of Agricultural, Food, and Resource Economics of Rutgers University. Rockefeller Foundation funded the research. We designed and pretested the survey form in early November 1999 and trained CCAP and Rutgers staff to do the survey. Each farmer was interviewed once during the last two week in November and first week in December. 1999. In this area all of the cotton had been harvested by the time the interview took place, and most of it had been sold. Therefore, production and sales information was fresh in farmers' minds.

The sample was a stratified random sample. The counties where the survey was conducted were selected so that we could compare Monsanto's Bt cotton variety, CAAS Bt varieties and conventional cotton. Hebei had to be included because it is the only province in which Monsanto varieties have been approved for commercial use. Within Hebei province Xinji county was chosen because that is the only place where newest CAAS genetically engineered variety is grown. We chose the counties in Shandong Province because the CAAS Bt cotton variety GK-12 and some non-Bt cotton varieties were grown there. After the counties were selected, the villages were chosen randomly. Within the selected villages the farmers were randomly selected from the villages' list of farmer and then these farmers were interviewed.

The final sample consisted of 283 farmers from five counties (nine villages) of Hebei and Shandong provinces. Table 2 shows the distribution of different varieties in our sample. The farmers in Hebei province all used either 33B or the new CAAS variety SGK321. In Shandong more than a third of the cotton was planted with 33B despite the fact that MDP was not selling it there. This sample is comprised of small farmers and poor. On average farmers had 0.75 ha of land per family. The average family income was 8,015 RMB (US$966).[10] The average per capita income was 2,047 RMB (US$247).

4. ECONOMIC IMPACT

The economic impact of Bt cotton is measured by a combination of changes in cost of production and changes in price of cotton due to the introduction of Bt cotton varieties. In this study the changes in cost and price per unit area are estimated using the farmer-level survey and then aggregated using available data on the area planted with these new varieties.

(a) *Impact on cost*

The mean yield per ha of different varieties from our sample is shown in column (1) in Table 3. Contrary to our expectations, variety 9418, a new, non-Bt variety which the government classifies as susceptible to bollworm, had the highest yield per ha (column 1, Table 3). One might also expect that better pest control would lead to lower yield variation, but the standard deviation (column 2) of the main varieties in our survey were not statistically different from each other.

Previous data from government trials and industry found that Bt cotton outyielded non-Bt cotton even when it was treated with pesticides. In government variety trials in 10 locations around Hebei Province in 1995, 33B yielded 45% more than the local non-Bt variety when the non-Bt variety was treated with pesticides and 86% higher if the non-Bt variety was not treated (Hebei Government, 1996) A Monsanto-financed study in 1998 of a random sample of 2,500 farmers in Hebei Province found that MDP's 33B outyielded non-Bt varieties by 39% (Deng, 1999). Government trials in Anhui in 1998 showed 33B yielding 9% more than treated non Bt varieties and a newer variety MDP variety yielding 28% more than the treated check variety.[11] In Liangshan County of Shandong Province a CAAS survey found that in farmer's fields CAAS varieties out yielded non Bt varieties by 375 kg of lint/ha (Jia Shirong, 1999).

The non-Bt variety in our sample had the higher yields for several reasons. The first reason may be the location of our samples. In 1999 yields of cotton in Shandong Province were higher than Hebei (1999 Shandong cotton yields were 2.7 mt/ha compared to 2.4 mt/ha in Hebei—Foreign Agricultural Service 2000). To control for some of the differences in climate, soil, and other factors, columns (4) and (5) in Table 3 compare only those farmers who grew both non-Bt and Bt varieties. All of these farmers are in Xiajin County in Shandong

Table 3. *Yields by variety—entire sample and farmers growing non-Bt varieties 1999*[a]

Variety	Entire sample			Farmers growing non-Bt varieties (Shandong)	
	Mean yield of seed cotton kg/ha[b] (1)	Variability of yields (S.D.) (2)	Number of observations (3)	Yield of seed cotton (kg/ha) (4)	Number of observations (5)
Bt cotton					
33B	3439	550	178	3670	16
SGK321[c]	NA	NA	42	4080	2
GK12	3495	591	77	3650	3
Other Bt varieties	3426	NA	33	3763	8
Non-Bt cotton					
Bollworm resistant varieties	2841	NA	17		
All susceptible varieties	3389	NA	35		
Non-Bt susceptible variety 9418	3700	585	27	3700	27

[a] *Source*: Survey.

[b] We conducted an *F*-test and found that non-Bt variety 9418 was statistically different from the Bt varieties.

[c] Variety SGK321 was planted late in the season because it was a new variety and researchers could not get the seed to farmers at the proper time. As a result its yields are not representative of what it can produce.

Province. Two Bt varieties—33B and GK—12 yield about the same as the non-Bt variety while several Bt varieties yield more than the non-Bt variety. This supports the argument that regional difference may be part of the reason the non-Bt variety does so well relative to Bt varieties.

The second possible reason that the non-Bt variety yields well is that it is also a new variety, which can outyield some of the Bt varieties in certain years. Variety 9418 was developed by the Cotton Research Institute of the Chinese Academy of Agricultural Sciences and was just released in the last few years. Thus, it is probably higher yielding than the check varieties that were in the government trials of the early government trials referred to above.

A third possible reason is that 1999 may be a year of low bollworm infestation. Bollworm populations fluctuate because of weather. If 1999 was a year in which the weather was not suitable for bollworm, non-Bt yields might be higher than in average years.

Finally, Delta and Pineland officials suggested that the performance of 33B in this sample does not really reflect 33B's characteristics because all of the 33B grown in Shandong and part of the 33B grown in Hebei was not seed purchased from Ji Dai. Some of the seed reported as 33B may be counterfeit, and the rest is farmer-saved seed which would not have had the same seed treatment as 33B and may have been mixed with other varieties.

To obtain the higher or similar yields from non-Bt varieties farmers had to spend more money on inputs and more on labor. Table 4 shows that farmers saved several hundred RMB per ha on seed costs by growing non-Bt seed, but they had to spend at least RMB 1,200 more per ha to purchase pesticides. Pesticides are applied by hand-powered sprayers. More applications of pesticide require a large increase in labor. Most of this labor is family labor. It was valued at the local farm labor wage. The cost of labor increased between 1,500 and 2,400 RMB/ha. Other input costs (irrigation, plastic, fertilizer, plant growth regulators, plowing and agricultural tax) also increased. In total the cost of non-Bt cotton was much more than the cost of the Bt varieties and overwhelms the savings due to lower seed costs and higher yield. The last two columns of Table 4 show that a kg of seed cotton produced using 33B cost only 80% of the cost of a kg of non-Bt cotton and GK 12 was 77% of the cost of non-Bt cotton.

(b) *Impact on cotton quality and net returns*

Costs were lower using Bt cotton, but if the price of the Bt cotton were also lower because of lower quality, farmers would not make a profit. China is gradually liberalizing marketing of cotton to let different enterprises trade cotton. In the area that we surveyed, however, all of the cotton that was not saved for seed and home use was sold to the government's Cotton and Jute Corporation. They purchased seed cotton at a fixed price which was modified by the quality of the fiber and the physical characteristics of the seed cotton. Most farmers in

Table 4. *Costs of production of Bt and non-Bt varieties entire sample 1999*[a]

Variety	Input costs (RMB[b]/ha)					Total cost	
	Seed (1)	Pesticide (2)	Labor (3)	Other inputs[c] (4)	Total cost[d] (5)	RMB/kg[d] (6)	As % of 9418 (7)
Bt cotton							
33B	547	244	5433	4476	10701	3.19	80
SGK321	571	131	3698	5911	10311	NA	NA
GK12	359	337	5391	4379	10466	3.09	77
Other Bt varieties	522	355	4513	3772	9161	2.68	67
Non-Bt cotton							
Bollworm resistant varieties	960	258	5525	4531	11273	4.45	112
Susceptible varieties	327	1799	6418	4784	13327	4.09	103
Non-Bt susceptible variety 9418	306	1996	6912	5073	14288	3.99	100

[a] *Source*: Survey.
[b] One US$ = RMB 8.3.
[c] Fertilizer, plastic, irrigation expenses, growth regulators, plowing expenses (the only mechanized operation), and land taxes. It does not include cost of irrigation equipment or land which are owned by the villages.
[d] We conducted an *F*-test and found that non-Bt variety 9418 was statistically different from the Bt varieties.

Table 5. *Prices, net income, and returns to labor*[a]

Variety	Sales of seed cotton		Costs of production	Net income	Non-labor input costs	Returns to labor
	Price[b] RMB/kg	No. of observations	RMB/kg	RMB/kg	RMB/kg	RMB/kg
	(1)	(2)	(3)	(4) = (1) − (3)	(5)	(6) = (1) − (5)
Bt cotton						
33b	3.24	176	3.19	0.05	1.58	1.66
SGK321	3.79	40	3.79	0.01	2.42	1.37
GK-12	3.61	34	3.09	0.52	1.50	2.11
Other Bt	3.52	18	2.68	0.84	1.35	2.17
Non-Bt						
Bollworm resistant	3.18	13	4.45	−1.27	2.27	0.91
Susceptible	3.32	32	4.09	−0.77	2.13	1.19
–9418	3.33	27	3.99	−0.66	2.08	1.25
Total	3.37	313	3.33	0.04	1.72	1.65

[a] *Source*: Survey.

[b] We conducted an *F*-test and found that non-Bt variety 9418 was not statistically different from the Bt varieties.

the survey sold their crop as seed cotton rather than lint. Table 5 column 1 shows that there is no quality premium for Bt or non-Bt varieties—most of the Bt varieties were sold at higher prices than the non-Bt varieties while 33B sold for slightly less. Farmers who sold SGK321 received higher prices because it is a new variety that seed firms were buying back at a premium to be used for seed.

To find out whether farmers' net income went up or down using Bt cotton, the cost per kg of seed cotton and the difference between prices and costs are shown in columns 3 and 4 of Table 5. Column 4 shows that the Bt varieties clearly are more profitable than the non-Bt variety. The net income from growing non-Bt varieties were negative, while the net income from all of the Bt varieties were positive. Perhaps more important to Chinese farmers, who do not hire much labor but do most of the work themselves, is the return to labor. This is calculated in columns 5 and 6 by subtracting the nonlabor cost from revenue. Again the Bt varieties have a clear advantage to farmers over the non-Bt varieties.

In summary, the main economic impact of Bt cotton is to reduce the cost of production of a kg of cotton between 20% and 33% depending on the variety and location. Quality of the lint may have changed for better or for worse, but it does not show up in the prices which farmers in our sample received. The net income and returns to labor of all of the Bt varieties are superior to the non-Bt varieties.

5. DISTRIBUTION OF THE BENEFITS

Are the farmers that get the benefit from these new technologies mainly farmers with large landholdings or wealthier farmers? The only places in China where large commercial farms grow cotton are the large state farms run by the army in Western China—mainly Xinjiang Province. Bollworm is not a major pest there although it has been growing in importance. Bt cotton is only grown on an experimental basis there. Small farmers grow the rest of the cotton. The average area of cotton planted by the farmers in our survey was about one-third of an acre.

The use and benefits from Bt cotton adoption by different groups of farmers based on size of farm and total income of the farm family is shown in Table 6. In general there is little difference in adoption or benefits from Bt adoption. Small farmers' adoption was about the same as adoption by larger farmers. Higher income groups adopted Bt cotton more completely than lower income groups. The most important finding is in the last column—smaller farms and farms which had lower incomes consistently obtained larger increases in net income than larger farmers and those with higher incomes.

Another important income distribution issue is how much of the benefits from Bt cotton were captured by seed companies and research institutes and how much went to farmers. Table 7 provides a rough estimate of the distribution

Table 6. *Distribution of benefits of Bt cotton adoption by size of farm or income class*[a]

	Bt as % of observations	Yield increase (kg/ha)	Change in chem cost (RMB/ha)	Change total cost (RMB/ha)	Change in net income (RMB/ha)
Farm size					
0.7–0.47 ha	86	410	−555	−1346	3331
0.47–1 ha	85	−134	−1691	−4429	3871
1 + ha	87	−124	−1186	−1510	1534
Household income					
1–10,000	85	170	−1117	−2503	3151
10,000+	91	65	−669	−449	1301
Per capita income					
1–1,500	85	456	−803	−1784	3702
1,500–3,000	83	8	−1212	−2355	2519
3,000+	97	−60	−87	6	−125

[a] *Source*: Survey.

of benefits between these groups. The model of the cotton market assumed for this calculation is shown in Figure 1. The demand curve is perfectly elastic since the government will procure all cotton offered (that meets certain quality standards) at a fixed price. The shift in the supply curve from S_0 to S_1 creates a producer surplus for farmers. The area between the supply curves under the demand curve is the producers' surplus and is approximated by area abQ_1Q_0.

Since the price of all the cotton varieties was about the same, farmers' benefits equal their cost savings per unit of Bt cotton produced times the quantity produced. The area under CAAS and MDP Bt cotton as reported by CAAS and MDP is at the top of the columns headed CAAS and MDP in Table 7. The "Farmers seed" column is a rough guess at the area under seed that spread from farmer to farmer not though MDP or CAAS related seed companies. Our survey found that one-third of the 33B seed planted in Hebei and all of the 33B in Shandong did not come from official sources and that a large part of the CAAS Bt varieties in Shandong came through unofficial channels. We assumed that the area of CAAS varieties planted with farmers' seed was equal to half the amount planted with CAAS seed and that farmers planted their own 33b seed on an area about equal to MDP seed.

The next row in Table 7—average yield/ha—is from Table 4. The row on cost savings by growing GK-12 or 33B instead of non Bt variety 9418 (columns (1) and (3) in Table 7) is the cost savings per kg from Table 4. In columns (2) and (4) the cost savings are adjusted upward by 0.05 and 0.08 RMD based on the money farmers in the survey reported they saved by using the lower priced unauthorized seed. The farmers' benefits from MDP varieties were at least RMB 275 million ($45 million) and possibly RMB 578 million ($69.6 million) while the farmers' benefits from CAAS varieties

Table 7. *Distribution of benefits between farmers, seed companies, and research institutes or research companies*[a,b]

	CAAS varieties		MDP varieties	
	CAAS (1)	Farmer seed (2)	MDP (3)	Farmer seed (4)
Area of Bt cotton 1999 (ha)	120,000	60,000	100,000	100,000
Yield (kg/ha)	3,500	3,500	3,440	3,440
Cost savings (RMB/kg)	0.90	0.95	0.80	0.88
Net benefits to farmers (million RMB)	378	200	275	303
Gross revenues to seed cos. (million RMB)	80	0	400	0
Returns to CAAS Monsanto (million RMB)	0	0	16	0

[a] *Sources*: Area from Table 1 and explained in text.
[b] Net benefits = savings of costs by farmers.
Gross revenues = quantity of sales from companies ∗ seed prices from survey.
Returns to MDP = RMB16/kg ∗ MDP quantity sales.

were at least RMB 378 million ($45 million) and possibly RMB 578 million.

In contrast the gross revenue of the seed companies that sold CAAS and MDP varieties was about RMB 80 million ($9.6 million) and 40 million ($5 million), respectively. They do not get any revenue from the "farmer-saved" seed. Most of the gross revenue goes to costs of seed production such as payments to the farmers that raised the seeds, costs of seed processing (delinting seed and treating it with pesticides), and costs of transportation and marketing. In fact, the seed companies that were partners with CAAS said that all of their revenue went to pay for their costs of purchasing seed from growers, processing seed, and marketing it. Therefore, they did not pay any of the royalties that CAAS was supposed to obtain from the sales. Of the RMB 40 million revenue earned by JiDai less than 40% went to MDP. [12] The rest of the gross revenue went to Ji Dai for costs of production and to Hebei Provincial Seed Company. Forty percent of the RMB 40 million is RMB 16 million or $1.9 million in 1999.

The benefits from Bt cotton went primarily to farmers. Using the data in columns 1 and 3 of Table 7, at least 82.5% of the 1999 benefits from the adoption of CAAS Bt cottons and at least 87% of the benefits of adopting MDP cotton went to farmers. [13] This is a very conservative estimate of farmers' benefits because it does not count any of the benefits from unauthorized use of CAAS and MDP seed (columns 2 and 4 in Table 7). Monsanto and Delta and Pineland's RMB 16 million was less than 6% of the RMB 275 million that farmers gained from MDP cotton adoption (column 3 Table 7).

6. ENVIRONMENTAL AND HEALTH AFFECTS

The previous section showed that the use of Bt cotton substantially reduced farmers' use of pesticides. Farmers continued to have to spray for early season insects but could substantially reduce or eliminate their use of pesticides to control bollworm during the middle and late part of the season. Some farmers reduced the number of times they sprayed from 30 times to three times. More often the reduction was from 12 to three or four sprays. Table 8 shows the differences in the quantity of pesticide used by families that only grew Bt cotton, only non-Bt cotton, and both. The quantity of formulated pesticide applied to non-Bt cotton was 48 kg per ha more than on Bt cotton or more that five times greater than Bt cotton. Assuming 320,000 ha of Bt cotton, its spread reduced pesticide use by at least 15,000 tons.

The survey found some preliminary evidence that this reduction of pesticide use may have had a positive impact of farmers' health. Farmers were asked if they had headache, nausea, skin pain, or digestive problems when they applied pesticides. Of the cotton growers that only used Bt cotton 11 farmers or 4.7% reported poisonings (Table 8). Of the farmers who planted both Bt and non-Bt cotton four farmers or 11% of the farmers reported poisoning. Of the farmers who only grew conventional cotton 2 or 22% reported poisonings.

The survey did not collect any evidence on the impact of Bt cotton on plant or insect biodiversity, but some evidence from other sources was collected. Regarding plant biodiversity, variety 33B has taken over 94% of

Table 8. *Environmental and health impacts 1999*[a]

Varieties of cotton cultivated	No. of farmers	Pesticide quantity[b] (kg/ha)	Number and seriousness of poisonings[c] reported in 1999 season					
			Required visit to		Went home to rest	Kept spraying	Total	Total as % farmers
			Hospital	Doctor				
Only Bt varieties	236	10.3	0	0	2	9	11	4.7
Both Bt and non-Bt varieties	37	29.4	0	0	0	4	4	10.8
Only non-Bt varieties	9	57.8	0	0	0	2	2	22.2

[a] *Source*: Survey.

[b] Total pesticide (active + inert ingredients).

[c] Farmers asked if they had headache, nausea, skin pain, or digestive problems when they applied pesticides.

cotton production in Hebei province (Bean, 1999) and is spreading rapidly elsewhere. Even though 33B dominates some areas, it is not clear that genetic diversity has been greatly or permanently reduced. These transgenic cotton varieties are not replacing genetically diverse landraces. They are replacing a few major varieties that were developed by government breeding programs most of which used genetic material from Delta and Pineland varieties that were brought into the country in the 1940s and 1950s (Stone, 1988). In 1994 one variety Zhongmain 12 covered 45% of the Hebei area (MOA, 1999).

In addition, 33B's dominance may be temporary. Several different Bt genes have been placed into at least six different cotton varieties and several new varieties have been approved for commercial use in 2000. These varieties seem to be competing successfully with 33B in Xinji County of Hebei and in Shandong Province. In Anhui MDP is introducing a different cotton variety which contains the same Bt gene as 33B.

Government extension agents found that insect diversity and the number of beneficial species of insects increased in fields of Bt cotton. In 1997 in Xinji county (Hebei Province) extension agents counted pests and beneficial insects on Bt cotton and non-Bt cotton with recommended pesticide applications. Bt fields had three bollworms per hundred plants while untreated fields had 100–300 worms. Bt fields had 31 species of insects of which 23 were beneficial species. In the conventional fields, which had been sprayed according to standard practices, they found 14 species of insects of which five were beneficial (Xinji, 1997).

7. PRELIMINARY CONCLUSIONS FOR POLICY MAKERS

(a) *Bt cotton increases farmers' income and reduces chemical use*

The central issues of this paper and of the debate about biotech in less-developed countries (LDCs) are: Will biotechnology help solve world food problems, increase the income of farmers and reduce pollution or will it increase pollution and enhance the profits of Monsanto at the expense of small farmers?

This study does not provide any direct evidence on the impact of biotechnology on world food supply. Cotton and tobacco—the two crops in which China reportedly had large areas of GE crops—are not food crops. So, biotech has not had any direct impact on food production in China so far.

The study does show that small farmers—even some of the smallest—obtain increased incomes from adopting Bt cotton. Farmers who grew the most popular Bt varieties reduced their costs of production by 20–23% over new non-Bt varieties while prices of cotton were about the same for Bt and non-Bt varieties. This substantially increased adopter's income. In addition it may allow some farm families that did not have enough food to increase their food purchases and food consumption.

Small farmers—those whose farms are less than one ha or have family incomes less than RMB 10,000—gained almost twice as much income per unit of land from adopting Bt cotton as large, more wealthy farmers gained. Consumers gained little from this technology because the government controlled cotton prices, and so increases in production did not push prices down. At most 18% of total social benefits from Bt cotton went to seed producer or research companies and institutes as revenue. CAAS received nothing in benefits, and at most 2.4% of total benefits from their varieties went to the Monsanto, Delta and Pineland, and Singapore Economic Development as royalties.

The use of Bt cotton has substantially reduced pollution by pesticides in the regions where it was adopted. It reduced the quantity of formulated pesticide use about 47 kg/ha, which implies a reduction in pesticide use of at least 15,000 tons. Farmers' and farm laborers' exposure to pesticides has been reduced, and we found preliminary evidence that pesticide poisonings were reduced due to Bt cotton.

Biodiversity of insects appears to have been enhanced by the adoption of Bt cotton. Local government authorities in Hebei province in 1997 found 31 insect species in Bt fields of which 23 were beneficial while non-Bt fields contained 14 species of which five were beneficial (Xinji, 1997).

(b) *Areas of continuing concern*

Resistance of bollworm to Bt cotton will eventually develop in China, but it is too early to tell whether it will take five years or 20. During the survey we asked farmers, county extension agents, seed companies, and scientists for evidence of resistance. They had not observed any resistance, but in many places Bt cotton had just been used one or two years. Thus, it is too early to have any strong empirical evidence on when resistance to Bt will start to show up.

The government needs to be continually watching for signs of resistance to Bt and develop policies to slow the development of resistance. The main policy in place at present is to develop new strains of Bt and to add other genes which also act as pesticides in plants. At present CAAS scientists and MDP officials argue there is no need for a policy of keeping part of each field as a refuge where susceptible varieties of bollworms can continue reproduce. [14] They argue that resistance will not develop quickly because many small farmers grow cotton in small, scattered plots, and there are many alternative hosts for bollworm—corn and some vegetables. Bt corn is now being field tested in China. If it is approved and spreads widely, there may be fewer alternative hosts for susceptible bollworm and more rapid development of resistance.

A second area of concern is that government incentives may prevent farmers from obtaining the maximum benefits from Bt cotton and other pesticidal crops. The government plant protection system has no incentive to push Bt cotton or to recommend that farmers adopt the lowest possible levels of pesticide use on Bt cotton. The government extension agency that is responsible for recommendations to farmers on pesticide use and for implementing integrated pest management, the Plant Protection Station, has to earn money to support their salaries by selling pesticides. In Gao Cheng County of Hebei Province half of the revenue of the plant protection stations was from the government and half was from selling pesticides (Gao Cheng plant protection officer, person communication November 6, 1999). Their incentive is to increase pesticide use, not reduce it.

A third concern is that Chinese farmers will not be able to obtain the best and safest plant biotechnology because of a series of government policies. First, county and provincial seed companies still have a monopoly on the sale of seeds of the most important crops. This prevents private and most other government enterprises from competing with them. Thus, government seed firms have little incentive to develop aggressively or spread new technology. Second, international seed companies other than Monsanto have not been allowed to enter the Chinese seed market unless they are willing to be minority partners in a joint venture. Even Monsanto's Bt cotton market has been limited to three provinces. None of the other international seed companies have been able to enter the Chinese seed market so far. This prevents Chinese farmers from getting rapid access to new technologies that these companies have commercialized elsewhere. Third, CAAS did not earn any royalties and Monsanto earned small returns (see Table 7) from its introduction of Bt cotton in part due to weak intellectual property rights. Low or nonexistent royalties mean that there will be little incentive for future research either by private companies or by public research institutes that have to earn money to support themselves.

(c) *Lessons for other LDCs*

Does the China example provide lessons for other LDCs? The answer appears to be yes. Many LDCs have the same problems—cotton pests that can no longer be controlled by pesticides, overuse of pesticides, and small farmers that cannot afford a lot of purchased inputs.

Bt cotton appears to be just what the critics of the Green Revolution wanted. It reduces small farmers' costs of production without reducing yields or quality. The technology is divisible. Even the smallest farmer can buy a small amount of seed and multiply it himself the next season. It reduces pesticide use which reduces the negative impact on the environment and human health.

There are still uncertainties about how durable this resistance to bollworm is and about environmental impacts of Bt cotton. But, when compared to the known environmental and health problems caused by pesticides, it would seem that Bt cotton is a desirable alternative. It may be particularly attractive in countries such as India which have major bollworm problems and no longer have effective ways of fighting them.

Not all plant biotechnology will have the same characteristics as Bt cotton. Herbicide resistant plant varieties have reduced pesticide use in the United States, but in some developing countries they may lead to increased use of pesticides. Many genetically engineered plants will be hybrids which farmers will have to buy each year from the company which will increase the company's share of the benefits. In addition, genetically engineered food crops which could increase food supply are about to reach the market. Thus, farmers and governments will have to pick and choose what biotechnology they wish to adopt.

In conclusion, our study suggests that more developing countries should seriously consider allowing the cultivation of Bt cotton because it offers an effective way of controlling a serious pest of cotton, reducing pesticide use, and improving the health of farmers and farm workers. In addition, LDC governments should be open to other biotechnology that passes their environmental and safety standards and allow farmers to choose the technologies that best fit their farming systems.

NOTES

1. Genetically engineering means "the selective, deliberate alteration of genes (genetic material) by man" (Nill, 2000). Thus, genetically engineered plants have had their genes modified by inserting genes or altering the expression of proteins by the genes. Genetically engineered plants are also called genetically modified plants.

2. Qaim (1999) is an example of one of the *ex ante* studies that try to project what the impact might be.

3. *Bacillus thuringiensis* refers to a group of rod-shaped soil bacteria found all over the earth, that produce "cry" proteins which are indigestible by—yet still "bind" to—specific insects' gut (i.e., stomach) lining receptors, so those "cry" proteins are toxic to certain classes of insects (corn borers, corn rootworms, mosquitoes, black flies, some types of beetles, etc.), but which are harmless to all mammals. Genes that code for the production of these "cry" proteins that are toxic to insects have been inserted by scientists since 1989 into vectors (i.e., viruses, other bacteria, and other microorganisms) in order to confer insect resistance to certain agricultural plants (Nill, 2000).

4. This history of CAAS Bt cotton is based on an interview with Professor Jia Shi-Rong and Fang Xuanjun of the CAAS Biotechnology Research Center, Beijing on 4 November 1999.

5. It is reportedly a combination of two genes which produce different types of Bt toxin—Cry1B and Cry1C.

6. This new system for inserting genes is called the pollen tube pathway system. Chinese scientists believe that this is a more efficient transformation process than other commercial transformation techniques, that antibiotic markers are not needed, and that the technique has not been patented elsewhere (personal communication with Professor Jia Shi-Rong, Beijing on 4 November 1999).

7. Provincial county seed companies plus government research institutes are the only institutions allowed to sell cotton seed. As government monopolies their prices have been controlled, and they do not have much incentive to innovate. The price of seed of cotton varieties has traditionally been low. They were not interested in selling cotton seed until they saw the high price that the Hebei Provincial Seed Company's joint venture with Monsanto was able to charge.

8. A chemical that is naturally coded for by a certain cowpea plant gene. It kills certain insect larvae by inhibiting digestion of ingested trypsin by the larvae, thereby starving the larvae to death (Nill, 2000).

9. The cotton market was liberalized for the first time in 1999 and prices fell considerable in the fall of the year. It is still appropriate, however, to model the market as perfectly elastic because the government purchased 72% of the crop and they determined the price through their manipulation of the stock of cotton, which is greater than the cotton produced in any one year, and export and import controls.

10. The official exchange rate between RMB and USs is 1.00 = RMB 8.3.

11. Data from government yield trials was provided by Delta and Pineland, December 1999.

12. County seed company officials in Xinji and Gao Cheng counties of Hebei Province reported in November 1999 that Monsanto and Delta and Pineland received 40% of sales revenue. Monsanto and Delta and Pineland could not give us the exact amount because it was proprietary information but did say that it was less than 40%.

13. This assumes that total benefits should be calculated as consumer and producer surplus plus profits of the companies selling the genetically engineered seeds (see Moschini & Lapan, 1997). We do not have figures on the profits of the seed companies. In order to be as conservative as possible about the share of farmers in the benefits, we have assumed that all of the revenue of the

seed companies is profits (which it clearly is not since they have to grow the seed, process it and market it). Thus, the percentage farmers capture is calculated by taking the producer's surplus of farmers (RMB 378 million from CAAS varieties and RMB 275 million from MDP) as a percentage of producer's surplus plus revenue of seed companies (80 million and 40 million).

14. This is the policy that the United States is using to try to slow down the development of resistance.

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