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GM SPECIAL ISSUE

Five years of Bt cotton in China – the benefits continue

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Summary

Bt cotton is spreading very rapidly in China, in response to demand from farmers for technology that will reduce both the cost of pesticide applications and exposure to pesticides, and will free up time for other tasks. Based on surveys of hundreds of farmers in the Yellow River cotton-growing region in northern China in 1999, 2000 and 2001, over 4 million smallholders have been able to increase yield per hectare, and reduce pesticide costs, time spent spraying dangerous pesticides, and illnesses due to pesticide poisoning. The expansion of this cost-saving technology is increasing the supply of cotton and pushing down the price, but prices are still sufficiently high for adopters of Bt cotton to make substantial gains in net income.

Keywords: Bt cotton, benefits, China.

Introduction

Despite growing evidence that *Bacillus thuringiensis* (Bt) cotton is increasing yields and reducing the use of insecticides and thus farmers' production costs in the USA (Perlak *et al.*, 2001), China (Pray *et al.*, 2001; Huang *et al.*, 2002a), South Africa (Ismael *et al.*, 2001) and Mexico (Traxler *et al.*, 2001), the critics of biotechnology continue to doubt its usefulness, particularly for small farmers in developing countries. GRAIN (2001) argues that Bt cotton does not have any positive impact on yield, and suggests that bollworms resistant to Bt are already becoming a problem in China.

This article documents the impact of Bt cotton in China using 3 years of farm-level surveys. In our earlier work we examined the impact of Bt cotton in China using data from a study of 283 farmers in Hebei and Shandong Provinces in 1999 (Huang *et al.*, 2002b; Pray *et al.*, 2001). These articles demonstrated that Bt cotton adoption led to positive and significant economic and health benefits for poor, small-scale farmers.

However, China's rural economy is evolving quickly and it may be that the environment has changed so much in the past several years that the benefits and costs of Bt cotton to farmers in China have also changed. Although the commercialization of cotton markets began in the late 1990s, most cotton was still purchased by the state Cotton & Jute Corporation in 1999 at a price fixed by the government. Since 2000, the government has allowed the price of cotton to fluctuate with market conditions. Cotton mills are now allowed to buy cotton directly from growers. On the input side, the New Seed Law passed in 2000 gave legitimacy to private seed companies and allowed them to operate in many provinces. These changes led to sharp changes in the price of cotton; increased Bt cotton seed availability; and changes in the pricing strategy of Bt cotton seed.

In the context of China's changing agricultural economy, the overall goal of this paper is to review the findings of our earlier papers which analysed the effects of Bt cotton adoption in 1999, along with the results of two follow-up surveys conducted in 2000 and 2001. Reports from government officials indicate that Bt cotton is spreading rapidly in the major cotton-growing regions of China. Our survey data on yields indicate that the adoption of Bt cotton continued to increase output per hectare in 2000 and 2001, and that the yield gains extend to all provinces in our sample. More importantly, Bt cotton farmers also increased their income by reducing the use of pesticides and labour. However, Bt cotton's success has attenuated its benefits. Rising yields and expanding area have begun to push cotton prices down. As a result, some of the gains that previously accrued to producers are now being enjoyed by consumers. Finally, data from the survey show that Bt cotton continues to have a positive environmental impact by reducing pesticide use. We provide evidence that farmers have fewer health problems because of reduced pesticide use. We conclude with evidence that China is not unique, and that there are lessons for other developing countries in China's experience.

History of development and adoption of Bt cotton in China

China has made a major investment in biotechnology research (Huang *et al.*, 2002b). These investments began in the mid-1980s and were accelerated in the late 1980s by the Ministry of Science and Technologies' 863 Project. (The 863 Plan, also called the High-Tech Plan, was initiated in March 1986 to promote high technology R&D in China. Biotechnology is one of seven supporting areas of the 863 Plan.) Unlike biotechnology research in most other countries of the world, the private sector has not played a major role in biotechnology research in China.

Insect pests, particularly the cotton bollworm (*Helicoverpa armigera*), have been a major problem for cotton production in northern China. China's farmers have learned to combat these pests using pesticides. Initially, farmers used chlorinated hydrocarbons (such as DDT) until they were banned for environmental and health reasons in the early 1980s (Stone, 1988). In the mid-1980s, farmers began to use organophosphates, but in the case of cotton, pests developed resistance. In the early 1990s, farmers began to use pyrethroids, which were more effective and safer than organophosphates. However, as in the case of other pesticides, China's bollworms rapidly began to develop resistance to pyrethroids in the mid-1990s. At this time, farmers resorted to cocktails of organophosphates, pyrethroids and whatever else they could obtain (including DDT, although the use of cholorinated hydrocarbons is illegal) – with less and less impact on the pests.

With rising pest pressure and increasingly ineffective pesticides, the use of pesticides by cotton farmers in China has risen sharply. Farmers use more pesticide per hectare on cotton than on any other field crop in China (Huang *et al.*, 2002a). In aggregate, cotton farmers use more pesticide than farmers of any other crop except rice (as the sown area of rice is many times more than that of cotton). Per hectare pesticide cost reached US$101 in 1995 for cotton, much higher than that for rice, wheat or maize, and many times more than the level applied by most other farmers in the world. Cotton production consumes nearly US$500 million in pesticides annually (Huang *et al.*, 2002b).

China's pest problems have led the nation's scientists to seek new pesticides, to breed cotton varieties for resistance to pests, and to develop integrated pest management programmes to control the pests. Consequently, when the possibility of incorporating genes for resistance to the pests came closer to reality, China's scientists started working on the problem. With funding primarily from government research sources, a group of public research institutes led by the Chinese Academy of Agricultural Sciences (CAAS) developed Bt cotton varieties using a modified Bt fusion gene (*Cry1ab* and *Cry 1Ac*). The gene was transformed into major Chinese cotton varieties using China's own methods (pollen-tube pathways). Researchers tested the varieties for their impact on the environment and then released them for commercial use in 1997 (Pray *et al.*, 2001).

Monsanto, in collaboration with the cotton seed company Delta and Pineland, developed Bt cotton varieties for the USA which were approved for commercial use there in 1996. They began to collaborate with the Chinese National Cotton Research Institute of CAAS at Anyang, Henan in the mid-1990s. Several of their varieties worked quite well in China. In 1997, several varieties were approved by the Chinese Biosafety Committee for commercialization. At the same time, scientists in the Cotton Research Institute were working on their own varieties, and the research team began to release their varieties in the late 1990s.

As Bt cotton has spread, government research institutes at province and prefecture levels have also produced new Bt varieties by back-crossing the Monsanto and CAAS varieties into their own local varieties. These varieties are now spreading in Henan, Shandong and elsewhere. Interviews with officials from local seed companies in July 2001 confirmed that such practices were widespread in almost every province in North China.

At present, CAAS has permission from the Biosafety Committee to sell 22 Bt cotton varieties in all provinces of China. The Biosafety Committee has approved the sale of five Delta and Pineland Bt varieties in four provinces (Hebei, Shandong, Henan and Anhui; Len Hawkins, Delta and Pineland, Beijing, personal communication). Many other varieties from national institutes (such as the Cotton Research Institute, Anyang) and from provincial institutes are being grown, but some of these local varieties do not go through the official approval procedure set by the Chinese Biosafety Committee.

In the wake of the commercialization of these approved and non-approved varieties, the spread of Bt cotton has been very rapid. From nothing in 1996, provincial officials, research administrators and seed company managers

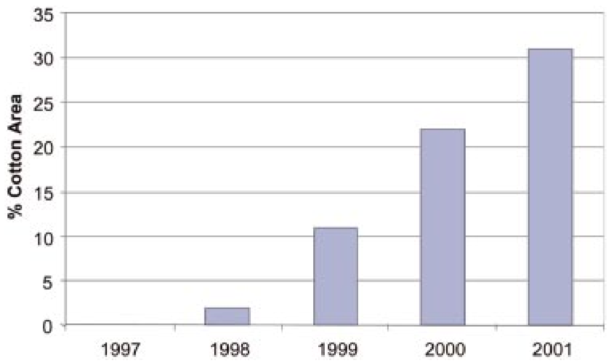

Figure 1. Adoption of Bt cotton.

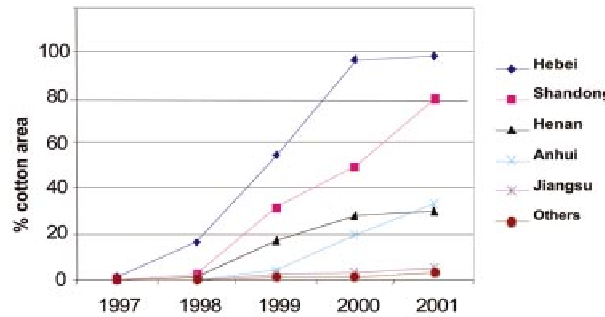

Figure 2. Spread of Bt by province.

estimate that farmers are planting nearly 1.5 million ha of Bt cotton (Figure 1). This means that approximately 31% of China's cotton area was planted to Bt cotton in 2001.

While the spread of Bt cotton has relied on the varieties introduced by the public research system and seeds sold (at least initially) by the state-run seed network, the adoption of Bt varieties has been the result of decisions by millions of small-scale farmers. Our survey indicates that, on average, each farmer growing Bt cotton in 1999 grew it on 0.42 ha. This suggests that about 3.5 million farms had adopted Bt cotton in 2001.

Figure 2 shows the spread of varieties by province. A few thousand hectares were planted in Hebei for seed production in 1997. Commercial production by farmers began in 1998 in the Yellow River cotton region of Hebei, Shandong and Henan. It spread rapidly to 97% of the cotton area in Hebei by 2000, and to 80% of Shandong by 2001. In Henan it appears to be levelling off at about a third of the cotton area. In the southern provinces of Anhui and Jiangsu, Bt cotton was adopted a year later than the other provinces; it is spreading fairly rapidly in Anhui. There are small amounts of Bt cotton planted elsewhere, including Xinjiang in the west.

Surveys

To assess the impact of biotechnology in China, we conducted a series of surveys in 1999, 2000 and 2001. In each successive year we increased the size of our sample and the provinces covered as Bt cotton spread. In 1999, we began with a sample of 283 farmers in Hebei and Shandong. 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 the 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 had been selected, villages were chosen randomly. Within the selected villages, farmers were randomly selected from the villages' lists of farmers, and these farmers were interviewed.

In the second year we included Henan Province so that we could assess the efficiency of Bt cotton by comparing it to the conventional cotton varieties that were still being grown there. Henan is in the same Yellow River cotton-growing region as Hebei and Shandong, and has similar agronomic and climatic characteristics. In 2001 we added Anhui and Jiangsu provinces because Bt cotton had now spread further south. As in 1999, counties were selected so that they would contain both Bt and non-Bt cotton producers. In the second phase of sample selection, villages and farmers were selected randomly. In 2000 and 2001 we also continued to survey the same villages in Hebei and Shandong that were surveyed in 1999. The total number of farmers interviewed increased to about 400 in 2000 and 366 in 2001.

Impact on yield, pesticide use and costs of production

In China, Bt cotton was developed in order to provide more effective protection against pests. Scientists expected that farmers who grew Bt cotton would be able to substantially reduce the amount of pesticide and gain better control of bollworm, which would reduce production costs and increase yield. Scientists expected that Bt cotton would yield more per hectare because it would reduce the damage that bollworms caused on cotton even with the best available chemical pesticides.

In the provinces that still grew some non-Bt cotton in 2001, the mean yield of Bt cotton varieties was 5–6% higher than the yields of the non-Bt varieties (Table 1). For all farms in the sample, Bt varieties were about 10% higher-yielding in 2001. This is consistent with the 8% yield increase due to Bt cotton in 1999, which we found using

Table 1 Yield of Bt and non-Bt cotton in provinces sampled, 1999–2001

	Number of plots			Yield (kg ha^{-1})		
Location/type	1999	2000	2001	1999	2000	2001
Hebei						
Bt	124	120	91	3197	3244	3510
Non-Bt	0	0	0	na	na	na
Shandong						
Bt	213	238	114	3472	3191	3842
Non-Bt	45	0	0	3186	na	na
Henan						
Bt		136	116		2237	2811
Non-Bt		122	42		1901	2634
Anhui						
Bt			130			3380
Non-Bt			105			3151
Jiangsu						
Bt			91			4051
Non-Bt			29			3820
All samples						
Bt	337	494	542	3371	2941	3481
Non-Bt	45	122	176	3186	1901	3138

Cotton production in Henan was seriously affected by flood in 2000, which lowered the yield. Counties included in the surveys are: Xinji (1999–2001) and Shenzhou (1999–2000) of Hebei province; Lingshan (1999–2001), Xiajin (1999–2000) and Lingxian (1999–2000) of Shandong province; Taikang and Fugou of Henan province (2000–01); Dongzhi, Wangjiang and Susong of Anhui province (2001); and Sheyang and Rudong of Jiangsu province (2001).

Table 2 Pesticide application (kg ha^{-1}) on Bt and non-Bt cotton, 1999–2001

Year	Location	Bt cotton	Non-Bt cotton
1999	All samples	11.8	60.7
	Hebei	5.7	
	Shandong	15.3	60.7
2000	All samples	20.5	48.5
	Hebei	15.5	
	Shandong	24.5	
	Henan	18.0	48.5
2001	All samples	32.9	87.5
	Hebei	19.6	
	Shandong	21.2	
	Henan	15.2	35.9
	Anhui	62.6	119.0
	Jiangsu	41.0	47.9

Red spider mite was the most serious problem in Anhui and Jiangsu in 2001, while bollworm was less serious.

econometric techniques that examined the impact of Bt adoption on yields after accounting for other inputs (Huang *et al.*, 2002a).

Yields of Bt cotton in the provinces that have used them for several years have also increased. Thus, according to our data, there is no obvious deterioration of the effectiveness of Bt varieties over time. The increasing yields also counter suggestions that bollworms are becoming resistant to Bt cotton. Instead, the trends in our sample suggest that farmers may be learning to manage the Bt varieties better, and are obtaining higher yields by making better use of the advantages that Bt varieties offer.

Our data also demonstrate that Bt cotton varieties continue to reduce total pesticide use. Table 2 shows that pesticide use has remained low in the states that adopted Bt cotton first – Hebei and Shandong. In the provinces Henan and Anhui, where Bt cotton was recently introduced commercially, the mean application of pesticides was reduced by 24–63 kg ha^{-1}. Only in Jiangsu, where red spider mite rather than bollworm is the main pest (Hsu and Gale, 2001), was the reduction in pesticide small – only 7 kg ha^{-1}. This suggests that the spread of Bt cotton may slow down as it moves away from the centre of the region in which bollworms have historically been the major pest (Hebei and Shandong). The reason for the slow adoption in Jiangsu appears to be that bollworm is not as much of a pest problem. As a consequence, the economic benefits from Bt are not great – especially at the higher prices of Bt seed in this region. In Henan, bollworm problems are as important as in Hebei, but the problem appears to be that farmers can only buy inferior varieties of Bt cotton. There is a virtual monopoly on seed production and sales by the Provincial Seed Company supplying varieties from the local research institutes. In addition, for some reason China's Biosafety Committee has refused to allow 33B or 90B to be grown in the province. Thus farmers have to grow illegal '33B' and CAAS varieties supplied by private seed traders, or local Bt varieties that have not approved by the Biosafety Committee. Part of the problem of the Henan varieties is that the level of Bt expression in those varieties falls by mid-season (Wu, 2002).

However, our sample does appear to show some increase in pesticide use per hectare on Bt cotton in 2000/2001 over 1999 when we examine the entire sample (Table 2). Most of this increase is due to the addition of high pesticide-use provinces in the south – Anhui and Jiangsu – where red spider mites rather than bollworm is the main pest. In those provinces for which we have data over time, the record of pesticide use per hectare is mixed. In Hebei province, for example, it increased between 1999 and 2001; in Shandong, however, after increasing between 1999 and 2000, it decreased in 2001. Between 2000 and 2001 pesticide use per hectare fell.

While it is not possible to say definitively why increased pesticide use in 2000 occurred in some locations, there are several possibilities. One explanation could be that the higher use is just due to differences in naturally occurring fluctuations in pest pressure, so the increase would be expected to disappear over time. The changes could also be due to the fact that farmers have begun to save their seed instead of buying new seed, an act that could reduce the effectiveness of Bt protection as saved seed is of lower quality. It could also be that bollworms are beginning to develop resistance. However, there is evidence that this is not the case. The Institute of Plant Protection has been collecting bollworm moths and testing them for resistance to Bt since 1997: in 2001, the latest year for which data are available, they had not found any evidence of bollworm resistance to Bt cotton (Wu, 2002).

The impact of these changes on production costs and net income is shown in Table 3. The cost of seeds was greater for Bt varieties. However, this was offset by a much greater reduction in pesticide use and a reduction in labour, because Bt cotton farmers do not have to spend as much time spraying pesticide. The total cost per hectare of producing Bt cotton was much less than in non-Bt cotton in 1999 and 2001, but slightly higher in 2000, mainly due to higher fertilizer inputs in Bt cotton (Table 3).

Because of the higher yield of Bt cotton and because, as shown in our earlier work, the prices for Bt and non-Bt cotton were virtually identical, the output revenues for Bt cotton are higher than for non-Bt cotton (row 1, Table 3). After deducing total production costs from output revenues, Table 3 shows that net income (last row) from producing Bt varieties was higher than for non-Bt.

Impact on farmers' health and the environment

The reduction of pesticide use due to Bt cotton has been substantial (Table 2). In China, as pesticide is primarily applied with small backpack sprayers which are either hand-pumped or have a small engine, and as farmers typically do not use any protective clothing, applying pesticide is a hazardous enterprise – farmers almost always end up completely covered with pesticide. Hence it is important to know if the reduction in pesticide use can be linked to improved health. In the past, large numbers of farmers became sick from pesticide applications each year (Qiao *et al.*, 2000).

According to our data, by reducing the use of insecticides Bt cotton has also reduced the number of farmers who are poisoned by pesticides each year. Table 4 divides our sample of farmers into three groups: those who exclusively use non-Bt varieties; those who use both; and those who plant only Bt varieties of cotton. In the first group, a higher percentage of farmers reported poisoning in each year. The percentages were particularly high: 22 and 29% in the first 2 years. In contrast, between 5 and 8% of farmers who used only Bt cotton reported that they had become sick from spraying pesticides.

Perhaps most importantly, the total decline in pesticide use has been impressive. Using the differences in average pesticide use in Table 2 and the area reported in Figure 1, the declines can be calculated. In 1999 the reduction in pesticide use was ≈20 000 tons of formulated pesticide while in 2001, due to increased area under Bt and increased savings per hectare, it was 78 000 tons, or about a quarter of all the pesticide sprayed in China in the mid-1990s.

Impact on total cotton production and location of production

Bt cotton has rejuvenated cotton production in the Yellow River area of China (north China). Cotton production was at its highest level in 1991 when the region produced more

Table 3 Average costs and returns (US$) per hectare for all farmers surveyed, 1999–2001

	2001		2000		1999	
Cost	Bt	Non-Bt	Bt	Non-Bt	Bt	Non-Bt
Output revenue	1277	1154	1578	1013	1362	1265
Non-labour costs						
Seed	78	18	59	21	62	63[a]
Pesticides	78	186	52	118	31	177
Chemical fertilizer.	162	211	132	128	154	154
Organic fertilizer	44	53	41	18	28	34
Other costs	82	65	86	70	120	88
Labour	557	846	840	841	616	756
Total costs	1000	1379	1211	1196	1011	1271
Net revenue	277	–225	367	–183	351	–6

[a]Seed prices for conventional cotton were high because nine farmers reported growing a new variety, Bu Xiu cotton, which was supposed to have fewer labour and management inputs, and had seed costs of US$155 ha^{-1} (US$1 = 8.3 Yuan).

Table 4 Impact of Bt on farmer poisoning, 1999–2001

		Farmers planting:		
		non-Bt cotton only	both Bt and non-Bt cotton	Bt cotton only
1999	Farmers	9	37	236
	Number of poisonings[a]	2	4	11
	Poisonings as percentage of farmers	22	11	5
2000	Farmers	31	58	318
	Number of poisonings[a]	9	11	23
	Poisonings as percentage of farmers	29	19	7
2001	Farmers	49	96	221
	Number of poisonings[a]	6	10	19
	Poisonings a percentage of farmers	12	10	8

[a]Farmers were asked if they experienced headaches, nausea, skin pain or digestive problems when they applied pesticides.

than 3 million tons. Production in the Yellow River region then plunged to 1.4 million tons 2 years later, in 1993. This was largely due to a severe bollworm infestation, as well as increased labour costs in the region and changes in relative crop returns (Hsu and Gale, 2001). When Bt cotton started to spread extensively in the region in 1999, the cotton area increased. In Hebei and Shandong provinces the cotton area grew from 729 700 ha in 1998 to 876 100 ha in 2000 (NSBC, 2001). Farmers were responding to the pest-resistant characteristics of Bt cotton which allowed them to grow cotton successfully despite the bollworms, reduced their production costs and saved labour.

At the same time, cotton production in the Yangtze region (south China) has remained steady, while cotton production has risen gradually in the north-west. The north-west cotton region is basically irrigated desert. As a result there are fewer pest problems, higher yields, and higher fibre quality than in other regions of the country. The major problem is being so far away from cotton markets, which are primarily in the Yangtze region and to a lesser extent in the Yellow River region. To offset the costs of transportation and encourage more production in this region, the Chinese government provides subsidies for important inputs such as irrigation, mechanized tillage, planting and harvesting.

Other things being equal, the recent increases in production due to lower costs should have led to lower prices of raw cotton, which would have passed some of the gains from Bt cotton along to consumers. Instead, cotton prices went up between 1999 and 2000, and did not decline until 2001. Farmers in our sample received 3.4 yuan kg^{-1} for Bt cotton and 3.32 yuan kg^{-1} for conventional cotton in 1999. Prices of Bt and non-Bt cotton then went up to 4.45 and 4.42 yuan kg^{-1} in 2000, an increase of about 30%. In 2001 the price declined sharply to 3.02 and 3.07 yuan kg^{-1} for Bt and conventional cotton, a level ≈10% below 1999 prices.

These fluctuations in price – particularly the increase from 1999 to 2000 – are primarily due to changes in the structure of cotton markets, and other supply and demand factors. They probably have little to do with the introduction of Bt cotton. However, the decline between 2000 and 2001 may be partially due to Bt cotton. The Foreign Agricultural Service of USDA (US Embassy, 2002) reports that 'Improved yields over the past two years likely reflect the growing use of genetically modified Bt cotton ...' and '... driven by domestic production, cotton procurement prices hit record lows in early 2001'. The implications of the price trends are that, unlike 1999 when all of the gains went to producers, in the past several years, some of the gains from the adoption of Bt cotton are starting to be passed along to consumers. In this case the first set of consumers are the large cotton mills that produce yarn and cloth. Reports by the USDA (US Embassy, 2001) suggest that yarn and cotton cloth prices, like raw cotton prices, are subject to considerable downward pressure. Thus some of the gains due to Bt cotton are probably being passed along to consumers both in China and in the international market.

Despite the decrease in prices in 2001, farmers were still able to obtain increased net incomes of about US\$500 ha^{-1} by growing Bt cotton instead of non-Bt cotton (Table 3).

Is China different from other developing countries?

Many of critics of biotechnology have argued that the benefits from Bt cotton, which have been shared by over 4 million small-scale farmers in China, cannot be gained by producers in other developing countries. They argue that China's farmers are forced to grow Bt cotton. However, according to our survey results and field work these critics are wrong and do not understand China's agriculture. For more than two decades, and increasingly in the past 10 years, most of China's farmers make their own decisions about what to plant and what technology to use. In this way, China's farmers are like those of other countries. However, it is true that there are important differences between China and other developing countries that other countries need to consider when drawing lessons from China's experience.

First, China's farmers are no longer forced by the government to grow cotton. In fact, in recent years the opposite has been the case. In 1999, while pretesting our questionnaire, we explicitly asked farmers in Hebei Province if they were required to grow a certain amount of cotton. They reported that in the past the government did put pressure on them to grow cotton by requiring that each farmer sell a fixed quantity of cotton to the government. By the mid-1990s, although these quotas were still in place, in fact they were no longer effectively enforced. Moreover, nearly every farmer in the sample stated that by 1998 cotton quotas were entirely gone. Since then, the market for cotton has been further liberalized and farmers face even less pressure for cotton production – in recent years the government has been trying to discourage farmers from expanding cotton production, with little or no success (US Embassy, 2001).

Moreover, we found no evidence of pressure to buy Bt cotton. Government agencies have been providing conflicting messages about Bt cotton. Commercialized government seed companies and private seed companies encouraged farmers to buy Bt cotton seed. At the same time, however, plant protection stations and government-owned pesticide companies tried to discourage farmers from growing Bt cotton, so that they would buy more pesticides.

Like Indian, Pakistani, or Indonesian cotton growers, producers in China are primarily smallholders. On average, China's cotton farmers have even smaller farms than those in other countries. As they buy their seed in competitive markets and sell their output in a competitive market, they differ little in these respects from their counterparts in other countries.

The main difference from other countries is the major role of the public sector in providing GM technology. A large share of the Bt cotton varieties that farmers cultivate have been developed by scientists working in public research institutes and are sold by government seed companies. Political support from these scientists to allow commercialization of GM technology is one of the reasons that China approved the commercialization of GM crops earlier than most other developing countries (Paarlberg, 2001). In addition, the competition between local government firms and foreign firms in providing Bt cotton varieties is undoubtedly one of the reasons why the price of Chinese GM cotton seed is so low.

Conclusions

Bt cotton is spreading very rapidly in China, driven by farmers' demand for technology that will reduce the costs of pesticide application and exposure to pesticides, and will allow them to use their time more profitably. The evidence from 5 years' experience with Bt cotton is that this technology is extremely valuable to over 4 million smallholders in China. They have been able to increase their yield per ha, and reduce pesticide costs, the time spent spraying dangerous pesticides, and the number of incidences of pesticide poisoning.

As predicted by economic theory, the expansion of this cost-saving technology is increasing the supply of cotton and pushing down the price. We have not yet done the modelling required to estimate how much of the decline in prices is due to Bt cotton, but the good news is that prices are still sufficiently high for adopters of Bt cotton to make substantial gains in net income from Bt cotton.

The final part of this paper argues that China is similar to other developing countries in that farmers are making the decisions to adopt Bt cotton based on their assessment of the costs and benefits. They find it profitable, and so we would expect cotton growers on small farms in many other developing countries to achieve similar gains. Especially in countries such as India, where cotton growers face the same bollworm pressures and where bollworm has become resistant to many of the most common pesticides, farmers are likely to benefit greatly from this technology.

The other lesson from China is the importance of local biotechnology research. The fact that Bt cotton was developed by government researchers at about the same time that international companies were introducing it into China clearly made it more palatable to the government, and ensured a strong lobby in favour of the technology.

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