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Bt cotton benefits, costs and impacts in China

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Summary

The overall goal of this paper is to reexamine findings of earlier efforts that analysed the effect of *Bt* cotton adoption in 1999 with two follow-up surveys conducted in 2000 and 2001. Our survey data on yields and econometric analyses indicate that the adoption of *Bt* cotton continues 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 incomes by being reducing use of pesticides and labour inputs. Finally, survey data shows that *Bt* cotton continues to have positive environmental impacts by reducing pesticide use. We provide evidence that farmers have less 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 their experience.

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Preface

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Three key questions guide the research programme:

- What influences the dynamics of policy-making in different local and national contexts, and with what implications for the rural poor?
- What role can mechanisms of international governance play in supporting the national efforts of developing countries to address food security concerns?
- How can policy processes become more inclusive and responsive to poor people's perspectives? What methods, processes and procedures are required to "democratise" biotechnology?

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1 Introduction

Despite growing evidence that *Bacillus thuringiensis* (*Bt*) cotton reduces use of insecticides, cuts farmers' production costs, and increases yields in the United States, key countries that criticise biotechnology continue to doubt its usefulness, particularly for small farmers in developing countries. Examples of such countries include China (Pray *et al.* 2001; Huang *et al.* 2002a), South Africa (Ismael *et al.* 2001), and Mexico (Traxler *et al.* 2001). A recent article in the journal of *Genetic Resources Action International* (*GRAIN* 2001) argues that *Bt* cotton does not have any positive impact on yields and implies that bollworms are becoming a problem in China, even though they are resistant to *Bt* cotton.

Alternatively, research presented in this article documents the impact of *Bt* cotton in China using three years of farm level surveys. It builds upon earlier research where we examined the impact of *Bt* cotton in China using 1999 data from 283 farmers in Hebei and Shandong Provinces (Pray *et al.* 2001; Huang *et al.* 2002a, 2002b and 2002c). These recent articles demonstrated that adoption of *Bt* cotton led to positive and significant economic and health benefits for poor, small farmers.

However, China's rural economy is evolving rapidly. As a result, the rural environment may have changed so much in recent years that the benefits and costs from *Bt* cotton to Chinese farmers may have also changed. Although the commercialisation of cotton markets began in the late 1990s, most cotton was still purchased by the State 'Cotton and 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 changed pricing strategies for *Bt* cotton seed.

In the context of China's changing agricultural economy, the overall goal of this research is to review the findings of our earlier efforts that analysed the effect of *Bt* cotton adoption in 1999 and the results of two follow-up surveys conducted in 2000 and 2001. Reports from government officials indicate that adoption of *Bt* cotton is spreading rapidly in the major cotton growing regions of China. Our survey data on yields and econometric analysis indicate that the adoption of *Bt* cotton continues 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 incomes by being reducing use of pesticides and labour. However, *Bt* cotton's success has attenuated its benefits. Rising yields and expanding area has begun to push cotton prices down. As a result, some of the gains that accrued previously to producers are now being enjoyed by consumers. Finally, data from the survey shows that *Bt* cotton continues to have positive environmental impacts by reducing pesticide use. We provide evidence that farmers have less 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 their experience.

2 *Bt* cotton development and adoption in China

China has made a major investment in biotechnology research (Huang *et al.* 2002c). These investments started in the mid-1980s and were accelerated in the late 1980s by the Ministry of Science and Technologies' 863 Project.[1] Unlike biotechnology research in most other countries of the world, the private sector has not played a major role in biotech 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 (e.g. DDT) until they were banned for environmental and health reasons in the early 1980s (Stone 1988). In the mid-1980s, farmers began to use organo-phosphates; however, in the case of cotton, pests developed resistance. In the early 1990s, farmers began to use pyrethroids, which were more effective and safer than organo-phosphates. However, as in the case of other pesticides, China's bollworms began to rapidly develop resistance to pyrethroids in the mid 1990s. At this time, farmers resorted to chemical cocktails of organo-phosphates, pyrethroids and other chemicals (including DDT, although use of choloinate hydrocarbons is illegal) with less and less impact on pests.

With rising pest populations and increasingly ineffective pesticides, the volume of pesticides used by Chinese cotton farmers rose sharply. Farmers use more pesticides per hectare on cotton than on any other field crop in China (Huang *et al.* 2002a). And in the aggregate, Chinese cotton farmers use more pesticides than farmers of any other crop with the exception of rice, where the sown area for rice is many times that for cotton. Overall, Chinese cotton production expend nearly US$500 million on pesticides annually (Huang *et al.* 2002b).

China's pest problems have led the nation's scientists to pursue a variety of strategies including developing new pesticides, to breed new cotton varieties that are pest resistance, and to develop integrated pest management (IPM) programs for pest control. Consequently, when the possibility of incorporating genes for pest resistance came closer to reality, China's scientists became actively involved. With funding primarily from government research sources, a group of public research institutes led by the Chinese Academy of Agricultural Sciences 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 which were approved for US commercial use in 1996. They began to collaborate with the Chinese National Cotton Research Institute of the Chinese Academy of Agricultural Sciences (CAAS) at Anyang, Henan in the mid 1990s. In 1997, several varieties were tested and approved by the Chinese Biosafety

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[1] The "863" Plan, also called 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.

Committee for commercialisation. Concurrently, scientists in the Cotton Research Institute were working on their own varieties. The research team began to release their varieties in the late 1990s.

As the adoption of *Bt* cotton spread, China's government research institutes at the province and prefecture levels have produced new *Bt* varieties by backcrossing the Monsanto and CAAS varieties into their own local varieties. These varieties are now being adopted in Henan, Shandong and elsewhere. Interviews with officials from local seed companies and officials in July 2001 and August 2002 confirmed that such practices were widespread in almost every province in Northern China.

At present, CAAS has permission from the Biosafety Committee to sell 22 *Bt* cotton varieties in all Chinese provinces. The Biosafety Committee has approved the sale of five Delta and Pineland *Bt* varieties in four provinces. Many other varieties from national institutes like the Cotton Research Institute, Anyang, and provincial institutes are being grown, but some of these local varieties did not go through the official approval procedure set by the Chinese Biosafety Committee. In the wake of commercialisation of these approved and non-approved varieties, the spread of *Bt* cotton has been very rapid. From nil in 1996, we estimate that farmers planted more than 2 million hectares of *Bt* cotton in 2001 (Table 2.1). This means that 43 per cent of China's cotton growing area was planted with *Bt* cotton in 2001.

Table 2.1 *Bt* cotton adoption in China, 1997–2001

Year	Cotton area (000 hectare)		*Bt* cotton share (%)	Number of farmers adopted *Bt* cotton (million)	
	Total	*Bt*-cotton		High estimate	Low estimate
1997	4491	34	1	0.09	0.08
1998	4459	261	6	0.6	0.5
1999	3726	654	18	1.5	1.4
2000	4041	1216	30	2.9	2.6
2001	4810	2174	45	5.1	4.7

Source: Authors' estimates based the interviews of provincial officials, research administrators and seed company managers.

While the spread of *Bt* cotton in China 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 Chinese small farmers. Our survey estimates that between 4.7 and 5.1 million farms adopted *Bt* cotton in 2001 (Table 2.1).

Table 2.2 estimates the adoption rate (per cent) and area planted in *Bt* cotton by Chinese cotton-producing provinces. *Bt* cotton production began in 1997 when a few thousand hectares were planted in both Hebei and Henan farm fields for seed production. In 1998, commercial production of *Bt* cotton by Chinese farmers started in the Yellow River cotton-producing region of Hebei, Shandong and Henan. Production rapidly expanded to 97 per cent of the respective cotton growing areas in Hebei by 2000, and in Shandong by 2001. In Henan, the adoption rate reached nearly 70 per cent in 2001 (Table 2.2).

Table 2.2 *Bt* cotton adoption in China by province, 1997–2001

Year	Hebei	Shandong	Henan	Anhui	Jiangsu	Rest of China
Area (000 hectares)						
1997	13	0	9	0	0	0
1998	175	45	17	7	1	0
1999	227	242	125	21	8	5
2000	298	500	245	62	21	17
2001	410	710	584	165	63	25
Adoption rate (%)						
1997	3	0	1	0	0	0
1998	55	11	2	2	0	0
1999	85	66	17	7	3	1
2000	97	88	31	20	7	5
2001	98	97	68	45	16	7

Source: Authors' estimates based on interviews of provincial officials, research administrators and seed company managers.

In the southern provinces of Anhui and Jiangsu, *Bt* cotton production started in 1998. Use increased fairly rapidly in Anhui, where, within 4 years *Bt* cotton adoption rate reached 45 per cent. Less rapid adoption of *Bt* cotton occurred in Jiangsu. This is probably due to two facts observed during our field survey. (1) Farmers in the province told us that the red spider problem is more serious than bollworm in their cotton production. (2) Several varieties of hybrid cotton from China's Cotton Research Institute and their provincial academy have been performing well in terms of yield. Additionally, there are small amounts of *Bt* cotton planted in Jiangxi and Hubei within the Yangtze River Basin; Shanxi and Shaanxi within the Yellow River Basin and elsewhere, including Xinjiang in Western China.

3 Data and 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 our sample size and the number of provinces surveyed as the use of *Bt* cotton spread throughout China.

In 1999, we began with a sample of two counties in Hebei and three counties in 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 was the only province in which Monsanto varieties had been approved for commercial use. One of two counties surveyed in the Hebei province was Xinji county, chosen because it is the only place where the newest CAAS genetically engineered variety was grown. We chose counties in Shandong province because the CAAS *Bt* cotton variety GK-12 and some non-*Bt* cotton varieties were grown there. After selection of provinces and counties, in the second phase of sample selection, two villages from each county were randomly selected. Finally, a sample of about 25–30 farmers (the number varies with village size) from each village was randomly selected by our survey team based on the entire list of farmers in the village, provided by the local household registration office. Each farmer was interviewed by trained numerators from the Center for Chinese Agricultural Policy for about 2–3 hours. The total number of farmers in our 1999 survey sample was 283.

In 2000, we included two additional counties in Henan province to assess the efficiency of *Bt* cotton compared to conventional cotton varieties grown there. Henan is in the same Yellow River cotton growing region as Hebei and Shandong and has similar agronomic and climatic characteristics. As we did in 1999, counties were selected based on the inclusion of both *Bt* and non-*Bt* cotton producers and the same sampling rules for selection of villages and farmers were followed. In 2000, we continued to survey the same villages in Hebei and Shandong, which we surveyed in the 1999. The total number of farmers interviewed increased to 407 in 2000.

In 2001, we added Anhui and Jiangsu provinces because the use of *Bt* cotton had spread further south. We followed a similar sampling approach as that used in 1999 and 2000 for the selection of counties, villages and farmers. However, in our quest to compare the use of *Bt* and non-*Bt* cotton production, we now had to drop some of the farmers previously surveyed in our 1999 and 2000 sampled villages in Hebei and Shangdong and two villages (from one county) in Henan because they had fully adopted *Bt* cotton in 2001. Thus, the total number of farmers interviewed in 2001 was 366.

4 Performance of *Bt* cotton in farm fields

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 pesticides used and have better control over bollworm pests. This, in turn would reduce costs of production and increase yields. Scientists expected that *Bt* cotton would yield more per hectare because of reduced damage from bollworms.

4.1 Yield impacts

Data within Table 4.1 show that *Bt* cotton variety yields are higher than those of non-*Bt* varieties. For example, in 2001 when comparing yields for all of surveyed farms, *Bt* varieties were about 10 per cent higher. This is consistent with previous findings using econometric techniques, where an 8–15 per cent yield increase was due to the adoption of *Bt* cotton in 1999 (Huang *et al.* 2002a).

Additionally, increased yields of *Bt* cotton occurred over time in provinces that have used *Bt* cotton for several years. Thus, according to our data, there is no obvious deterioration of the effectiveness of *Bt* varieties over time. These 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 better manage *Bt* cotton varieties, thus obtaining higher yields.

Table 4.1 Yield of *Bt* and non-*Bt* cotton in sampled provinces, 1999–2001

	Number of plots			**Yield (kg/ha)**		
	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

Note: Cotton production in Henan was serious affected by floods in 2000, which lowered yields. Surveyed counties included 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 (2000–2001), Dongzhi, Wangjiang and Susong of Anhui province (2001), and Sheyang and Rudong of Jiangsu province (2001).
Source: Authors' surveys.

4.2 Cost of production impacts

When comparing pesticide use on *Bt* cotton to that of non-*Bt* cotton in Table 4.2, our data demonstrates that *Bt* cotton varieties exhibit reduced pesticide usage. For the provinces that adopted *Bt* cotton first – Hebei and Shandong – Table 4.2 shows that pesticide usage has remained low. In the provinces of Henan and Anhui, where *Bt* cotton was recently introduced commercially, the mean application of pesticides has been dramatically reduced when compared to non-*Bt* cotton. Only in Jiangsu, where red spider mites are the main pest rather than bollworms (Hsu and Gale 2001), was the difference in pesticide use small between *Bt* and non-*Bt* cotton, only 7 kilograms per hectare. This suggests that the spread of *Bt* cotton may be reduced as it moves away from the regions in which bollworms have historically been the major pest–Hebei and Shandong. As a consequence, the economic benefits from producing *Bt* cotton are not as great, especially with higher *Bt* seed prices.

Table 4.2 Pesticides application (kg/ha) 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

Note: Red spider mite is the most serious problem in Anhui and Jiangsu in 2001, while bollworm is less serious.
Source: Authors' survey.

In Henan, bollworm problems are as important as in Hebei; however 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, China's Biosafety Committee has refused to allow the 33B or 90B varieties 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 been approved by the Biosafety Committee. Part of the problem for the Henan varieties is that the level of *Bt* expression is reduced by midseason (Wu 2002).

When looking solely at pesticide use per hectare on *Bt* cotton, our sample does appear to show some increase over time (Table 4.2). In those provinces in which we have data for all three surveyed years, results on pesticide use per hectare is mixed. In the Hebei province for example, pesticide usage increased between 1999 and 2001. In Shandong, however, after pesticide use per hectare increased between 1999 and 2000, it decreased in 2001. Precise assessment of impacts of *Bt* cotton on pesticide usage calls for a more methodologically oriented estimation, which is presented in the later part of this article.

4.3 Farmer income impacts

Table 4.3 includes data on average per hectare costs, returns and thus, net revenue (or income). Regarding inputs, seed costs were always greater for *Bt* cotton varieties compared to non-*Bt* varieties. However, this difference was offset by a much greater reduction in expenditures for pesticides and labour, since *Bt* cotton farmers did not have to spend as much time spraying pesticides. The total cost per hectare of producing *Bt* cotton was much less than that for non-*Bt* cotton in 1999 and 2001, but slightly higher in 2000, mainly due to higher fertiliser inputs.

Table 4.3 Average per hectare costs and returns (US $) for all surveyed farmers, 1999–2001

	2001		2000		1999	
	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]
Pesticide	78	186	52	118	31	177
Chemical fertiliser	162	211	132	128	154	154
Organic fertiliser	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 in 1999 because 9 farmers reported growing a new variety, "Bu Xiu Cotton," which was supposed to require less labour and management, however seed costs equaled $155/ha. $1=8.3 Yuan.
Source: Authors' surveys.

Output revenues for *Bt* cotton were higher than revenues for non-*Bt* cotton due to higher yields obtained by *Bt* cotton as shown in Table 4.1, assuming identical prices for *Bt* and non-*Bt* cotton. After deducting total production costs from output revenues, Table 4.3 shows that net income (last row) from producing *Bt* cotton varieties was higher than for non-*Bt* varieties.

5 Farmer health and environmental impacts

As shown in table 4.2, the reduction of pesticide use due to *Bt* cotton has been substantial. In China, since pesticides are primarily applied with small back-pack sprayers that are either hand-pumped or have a small engine and since farmers typically do not use any protective clothing, applying pesticides is a hazardous task, where farmers almost always end up completely covered with pesticides. Hence, it is important to know if the reduction in pesticide use can be linked to improved farmer health. In the past, a large numbers of farmers became sick from pesticide applications each year (Huang *et al.* 2001).

According to our data, by reducing the use of pesticides *Bt* cotton has also reduced the number of farmers who are poisoned annually by pesticides. Table 5.1 divides our sample farmers into three groups: (1) those who exclusively use non-*Bt* cotton varieties, (2) those who use both *Bt* and non-*Bt* varieties, and (3) those who plant only *Bt* cotton varieties. When comparing the first group to other groups, a higher percentage of farmers planting only non-*Bt* cotton reported poisoning in each year, 1999 through 2001. The percentages were particularly high – 22 per cent and 29 per cent in the first two years. In contrast, between 5 and 8 per cent of farmers who used only *Bt* cotton reported that they had become sick from spraying pesticides.

Table 5.1 Impact of *Bt* on farmer poisoning, 1999–2001

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

[a] Farmers were asked if they had headache, nausea, skin pain, or digestive problems when they applied pesticides.
Source: Authors' surveys.

Perhaps most importantly, the total decline in pesticide use has been impressive. Using the differences in average pesticide use in Table 4.2 and the area planted in *Bt* cotton in Table 2.1, a rough estimate of the decline in pesticide usage can be calculated. In 1999, the reduction in pesticide use was more than 20,000 tons of pesticides. While in 2001, due to increased area planted in *Bt* cotton and subsequent reduction in pesticide use per hectare, a reduction of about 80,000 tons or about 25 per cent of all pesticides sprayed in China in the mid 1990s is estimated. We will re-estimate these figures after we present our econometric results below. This has significant implications for the environment, particular for the quality of drinking water for local farmers in cotton-producing regions, where farmers depend on ground water for both domestic and irrigation uses.

5.1 Production and price impacts

5.1.1 Production location and trends

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 nation produced more than 3 million tons. Production in the Yellow River region then plunged to 1.4 million tons 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: 19). In 1999 when *Bt* cotton started to spread extensively in the region, this cotton production area rebounded. In Hebei and Shandong provinces, planted cotton area went from 729,700 hectares in 1998 to 876,100 hectares in 2000 (NSBC 1999–2001). Farmers were responding to the pest-resistant characteristics of the *Bt* that allowed them to successfully grow cotton despite the presence of bollworms, as well as reduced their production costs.

Concurrently, cotton production in the Yangtze region (South China) has remained steady while cotton production has risen gradually in Northwest China. The Northwest cotton region is basically irrigated desert. As a result they have less pest problems, higher yields, and higher fiber quality than other regions of the country. Their major problem is being far away from cotton markets, which are primarily in the Yangtze region and to a lesser extent in the Yellow River region. To offset transportation costs and encourage more production in this region, the Chinese government provides subsidies for important inputs like irrigation and mechanised tillage, planting, and harvesting.

5.1.2 Price fluctuations

Other things held equal, 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 to consumers. Instead cotton prices went up between 1999 and 2000. They did not decline until 2001. In our 1999 sample, farmers received 3.4 yuan per kilogram for *Bt* cotton and 3.32 yuan per kilogram for conventional cotton. Prices of *Bt* cotton and non-*Bt* cotton then went up to 4.45 and 4.42 yuan per kilogram respectively, in 2000, an increase of about 30 per cent. In 2001, prices declined sharply to 3.02 and 3.07 for *Bt* and conventional cotton, respectively, a level approximately 10 per cent below 1999 prices.

These price fluctuations are primarily due to the changes in the domestic supply and demand factors and the changes in global cotton markets, the latter has been heavily distorted by the cotton farm subsidies in the exporting countries (i.e. US). According to a recent study by Fan (2002), he shows that adoption of *Bt* cotton in 1997–2001 reduced cotton price by about 3 per cent, textile industry in particular and consumer in general gains part of the benefits from farmers' *Bt* cotton adoption.

The implications of these price trends are that some of the gains from the adoption of *Bt* cotton are starting to be passed to consumers. In this case, the first set of consumers are the large cotton mills that produce yarn and cloth. Despite the decrease in prices in 2001, this simple descriptive budget analysis shows that farmers were able to increase net incomes by about $500 per hectare by growing *Bt* cotton instead of non-*Bt* cotton (Table 4.3).

To verify our survey results on *Bt* cotton – reduced use of pesticides and increased yields – the remainder of this article will develop an empirical model to measure the impacts of transgenic crops with pest resistance on pesticide use and yield. The models are then estimated using our survey data and the results of econometric estimation are presented.

6 Model and estimation results

6.1 Hypothesised impacts of Bt cotton on yield

As the pesticide use and yield performance of both *Bt* cotton and non-*Bt* cotton simultaneously depend on a number of factors (such as geographic and climate conditions, extent of pest stress, farmers' characteristics and production inputs, in the rest of this article), we empirically estimate a pesticide use function and use a production function approach to estimate the impact of *Bt* cotton on crop productivity. In the production function approach, we attempt to determine the value and impact on cotton production of two different types of variables: (1) damage abatement inputs, such as pesticide use and/or host plant resistant varieties including the *Bt* variety; and (2) conventional inputs, such as fertilisers and labour.

Ceteris paribus, the use of abatement inputs does not necessarily increase yields. Instead their primary role is to abate damage or keep output from falling. In contrast, the use of inputs, such as fertiliser and labour, contribute by directly increasing yields. When working to model and empirically track the impacts of pesticides and *Bt* varieties on output, attention needs to be given to the special nature of the these inputs. In production function analyses, the effect of damage abatement inputs must be measured assessing the amount of yield or output that was "recovered" by the use of damage abatement inputs. Following the works by Headley (1968) and Lichtenberg and Zilberman (1986), a damage abatement function can be incorporated into traditional models of agricultural production. However, unlike all but a few prior studies (including our own research on rice – Widawsky *et al.* 1998), we include host plant resistant varieties into this analysis, within the damage abatement approach.

In our study, we examine two damage abatement inputs: pesticides and *Bt* cotton varieties. Conceptually, *Bt* cotton varieties differ from chemical use only in the way that they control certain pests, since *Bt* cotton is a genetically engineered crop that produces a naturally occurring pesticide, the *Bacillus thuringiensis* (*Bt*) toxin. In this way, *Bt* cotton varieties are acting as an input that can substitute for the use of pesticides. Practically, one of the main production outcome differences between cotton farmers that use *Bt* varieties and those that do not, is the difference in the amount of pesticides required to control pests.

On the other hand, *Bt* varieties may increase yields for other reasons. Let us consider conventional varieties with higher yields but lower pest resistance. These higher-yield varieties might be neither approved for commercialisation nor largely adopted by farmers if insect resistance is low and adoption difficult. If the *Bt* gene is transferred into these higher-yield varieties, the spread of *Bt* cotton could generate higher yields than non-*Bt* varieties currently used by farmers. For the varieties that have been adopted by farmers, we also observed a large yield difference among varieties even when we controlled for the impacts of non-varietial factors.[2] The trade-off between high yield and high resistance is probably one of foremost explanations for this yield variation. Higher yields for *Bt* cotton compared to non-*Bt* cotton may also due to management practices, whereby crop production management of *Bt* cotton is easier than that for non-*Bt* cotton. Yield contribution of *Bt* cotton is also due to a more timely control of pest attack, which is partially captured in the impacts of abatement input, the *Bt* gene. Based on the above discussion, we have three hypotheses to be tested:

- Hypothesis 1: *Bt* cotton has a positive impact on the crop yield through shifting the crop yield frontier,

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[2] We examined production functions for cotton yield using conventional varieties (excluding *Bt* cotton varieties). The results showed that the dummy variables for a few varieties with small planting areas had significant positive parameters.

- Hypothesis 2: *Bt* cotton reduces yield loss through the abated damage, and
- Hypothesis 3: Pesticide impact on yield for non-*Bt* cotton is simply through the abated damage.

6.2 Yield model

The nature of damage control discussed above suggests that the observed crop yield, *Y*, can be specified as a function of both standard inputs, *X*, and damage control measures, *Z*, as:

(1) $Y = f(X)\, G(Z)$,

where the vector *X* includes conventional inputs (labour, fertiliser, and other inputs), farm-specific factors (i.e., farm household characteristics), location- and time-specific factors, and others (e.g., climate and natural disaster). The term, *G(Z)*, is a damage abatement function that is a function of the level of control agents, *Z* (in our case, Z includes the pesticides used by farmers to control pests during outbreaks and the *Bt* cotton variety). The abatement function possesses the properties of a cumulative probability distribution. It is defined on the interval of [0, 1]. When *G(.)* = 1, then a complete abatement has occurred for crop yield losses due to pest related problems with certain high level of control agent; when *G(.)* = 0, then the crop was completely destroyed by pest related damage. The *G(.)* function is non-decreasing in *Z* and approaches 1 as the damage control agent use increases. If we assume a Cobb-Douglas production function, *f(X)*, and if we assume that the damage abatement function, *G(Z),* follows an exponential specification,[3] then equation (1) can be written as

(2) $$Y = a\, \Pi_i^n X_i^{k_i}\, [1 - \exp(- c\, Z)],$$

where a, k_i, c are parameters to be estimated, and c is restricted to be positive. The i indexes inputs, including labour, chemical fertiliser and materials inputs (total material inputs minus chemical fertiliser). The variable Z represents pesticide use. The model in equation (2) could be estimated for *Bt* cotton and non-*Bt* cotton separately.

However, in order to test our hypotheses, we pool data on *Bt* and non-*Bt* cotton to estimate a more general damage control production function with the following assumptions on the nature of the *Bt* and pesticide interactions:

(3) $a = a_0 + a_1\, Bt$

(4) $c = c_0 + c_1\, Bt$

where *Bt* is a dummy variable with a value of 1 for *Bt* cotton varieties and 0 otherwise.

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[3] We also use Weibull and other different functional forms in our analysis since as Fox and Weersink (1995) showed that results can be sensitive to functional form. But none of these models converged even when using a very high level converging criteria.

6.3 Pesticide use model

The models specified above do not account for one potential statistical problem, the endogeneity of pesticide use in the production function. Since pesticides are applied in response to pest pressure (which is not controlled for in this analysis), high levels of infestations may be correlated with lower yields. Hence, it is possible that the covariance of Z and the residuals of the yield function is non-zero, a condition that would bias parameter estimates of the impact of pesticides on output. In other words, pesticides used by farmers may be endogenous to yields and a systematic relationship may exist among pests, pesticide use, and cotton yields.[4]

To avoid this possible econometric problem, we adopt an instrumental variable (IV) approach. To develop an instrument for pesticide application that is correlated with actual pesticide use but does not affect output except through its impact on pesticides, a pesticide use model is first estimated. The predicted values of the pesticide use can then be used in the estimation of model (2). As long as a set of variables in the pesticide use equation exists to explain pesticide use and these variables do not have any independent explanatory power on yields, the IV approach should allow us to better examine the impacts of *Bt* and pesticides on cotton output and the interactions of these two pest control technologies.

To implement the IV identification strategy, we hypothesise that a number of control variables—such as household characteristics (*age, village leader, Bt cotton training*, and *education)*, cotton variety related dummy variables (*Bt* vs. non-*Bt*, coated vs. non-coated seed, and hybrid vs. non-hybrid seed), and four provincial dummy variables—can be included in both the yield and pesticide use equations. In addition, we posit that pesticide use depends on the profitability of its use.[5] We include three measures to incorporate this effect: (1) the farmer's perception of the severity of the farm's pest infestation problem (*Yield Loss*—measured as the per cent of the crop that the farmer believes would have been lost if the crop were not sprayed); (2) the price of pesticides (*Price*—measured as yuan per kilogram); and (3) total cultivated land or farm size (not cotton area). *Price* is measured as the unit value price of pesticide purchased by the farmer. We calculate the unit value price for each household by dividing the value of

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[4] Theoretically, farmer's adoption of *Bt* cotton should also be treated as the other endogenous variable. However, the adoption of *Bt* cotton in our sampled areas is strongly associated with the commercialisation policy of genetically modified products in China and the public seed distribution system within the region where *Bt* cotton has been approved for commercialisation. Estimation of *Bt* cotton adoption was tried, but no robust results were obtained and all damage control models with *Bt* cotton as endogenous variable could not converge at reasonable levels of convergence criteria.

[5] Beach and Carlson (1993) showed that farmers are also motivated in their use of *Bt* varieties by their concerns for water and health quality. While this may well be true for farmers in our sample (which would mean we should include variables that reflect such concerns), our survey did not collect information that could be used to create variables to control for these factors. Although unfortunate, the main reason for estimating the pesticide use equation is for identifying the effect of pesticide use in the yields equations. Hence, as long as the instruments that we do have are successful as instrumental variables, an incomplete specification of the pesticide use equation is of less concern.

their pesticide purchases by the quantity that they purchased.[6] Logically, the three instrumental variables meet the criteria of appropriate instruments (they affect the endogenous variable, *Pesticide*, but not yields, except through their impact on pesticide use). The IVs also pass the Hausman-Wu exclusion restriction statistical tests.

In summary, following our above discussion, farmer's pesticide adoption (*Pesticide*) model can be explained by the following equation:

(5) Pesticide use = f (*Yield loss, Price, Farm size; Age, Education, Village leader dummy, Training dummy, Coated seed dummy, Hybrid seed dummy, Bt cotton dummy and dummies for flood, provincial and years*)

where the first three variables on the right hand side of equation (5) are the instruments, and the others are the control variables. More specifically, in equation (5), we include *Bt cotton dummy,* a dummy variable with a value equal to 1 when the farmer uses *Bt* cotton, and 0 otherwise. We also include the other seed related dummies, *Coated seed and Hybrid seed*, *Age, Education, Village leader dummy,* dummies for *flood and provinces* to control for other impacts. In equation (5), the dependent variable, *Pesticide use*, is defined in terms of quantity (measured as kilograms per hectare). An alternative specification, using pesticide cost (yuan per hectare), generates similar results. Therefore, only the results from one of these two specifications are presented. In the two-equation system, the models (2) and (5) are estimated by nonlinear methods and two-stage least squares estimation procedures. In order to compare the results from the traditional production approach, we estimate a Cobb-Douglas production function using ordinary least squares (OLS), where pesticide use and *Bt* cotton adoption are specified the same as other inputs such as labour and fertiliser.

As there is a concern for potential bollworm resistance to the *Bt* gene over time, we further specify the *Bt* cotton dummy variable in equation (5) into the following three components:

(6) $$b_0\,Bt + b_{2000}\,Bt\,t_{2000} + b_{2001}\,Bt\,t_{2001}$$

where b is parameter to be estimated; *2000* and *200l* are year index; t_{2000} and t_{2001} are year dummies for 2000 and 2001.

We have the following hypotheses to be tested:

- Hypothesis 4: *Bt* cotton reduces pesticide use. We fail to reject this hypothesis if b_0 is significantly less than zero.

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[6] In the survey we tried to weight quantities of pesticides by their kill-rate dosage. Unfortunately, not all farmers knew the strength of the pesticides that they had purchased and we obtained the information for only a subset of farmers. Consequently, our measure of pesticide quantity is an unweighted sum of the purchases. However, since the correlation coefficient between the unweighted measure and the weighted measure for those farmers that reported the complete information was greater then 0.50 (and significantly different than zero), we do not believe the use of unweighted measures will cause problems.

- Hypothesis 5: The resistance by cotton bollworms to the *Bt* gene has built up over time. This hypothesis is not rejected if and only if $b_{2000} > 0$ and $b_{2001} > b_{2000}$.

6.4 The results

6.4.1 Cotton yield impacts

Our analysis of the impact of *Bt* cotton and other pest control methods show the effect on cotton production. The production function analysis generates results that are typical of household studies done on China's agricultural sector (Ye and Rozelle 1994; Li 1999). The coefficients on the labour and fertiliser variables indicate that output elasticities for both labour and fertiliser are low; our estimated labour elasticities are nearly zero and fertiliser elasticities are about 0.11 to 0.13 (Table 6.1). Farmers in our sampled areas apply more than 400 kilograms of fertiliser per hectare, one of the highest application rates in the world. Labour use also exceeds 500 person-days per hectare. Therefore, such insignificant marginal contributions of fertiliser and labour to cotton production may be expected.

The results using the Cobb-Douglas production function approach indicate that although *Bt* varieties raise cotton yields, pesticide use is not effective in raising yields (Table 6.1, column 2). The descriptive statistics presented in Table 4.1 show the unconditional yields for *Bt* cotton users are about 5 to 10 per cent higher than those for non-*Bt* cotton users. When other inputs, human capital variables, time- and location-specific variables, and other factors are accounted for, *Bt* cotton users get an 8.3 per cent increase in yields in the Cobb-Douglas function (see the coefficient for the *Bt* cotton dummy variable in Table 6.1 column 2) and 9.6 per cent in the damage control function (Table 6.1, column 3). In regards to hypothesis 1, these results suggest that *Bt* cotton is effective in keeping yields higher than they would have been without *Bt* adoption. In other words, *Bt* cotton increases productivity through a shift in cotton yield function by about 10 percent.

The insignificance of the *pesticide use* coefficient in the Cobb-Douglas function can be interpreted to mean that (1) the marginal impact of pesticide use in cotton production is zero when pesticides are treated as a traditional yield-increasing input; or (2) pesticide impacts on yield is through the abated damage, our hypothesis 3.

If the damage control function specifications reflect the true underlying technology, our results suggest that (1) *Bt* cotton is also effective in reducing yield loss through the abated damage (c_1 is positive and statistically significant from zero, Table 6.1, column 3) – our hypothesis 2 is accepted; and 2) there is a statistically significant impact of pesticide use in reducing yield loss through the abated damage. This result together with insignificant parameters for pesticide variable in the Cobb-Douglas function strongly suggests that hypothesis 3 is accepted.

Using the parameters presented in Table 6.1, the damage abated functions, $G(Z) = 1 - exp(- c\ Z)$, for both *Bt* and non-*Bt* cotton are computed. By varying the level of Z (pesticide use), we can simulate the scales of abated damage. The simulation results are presented in Figure 6.1. Several notable results are observed for both *Bt* and non-*Bt* varieties. The damage abated increases significantly in the initial use of pesticide. The values for *Bt* cotton approach 1 much faster than non-*Bt* cotton, providing evidence of a better insect control measure for *Bt* cotton.

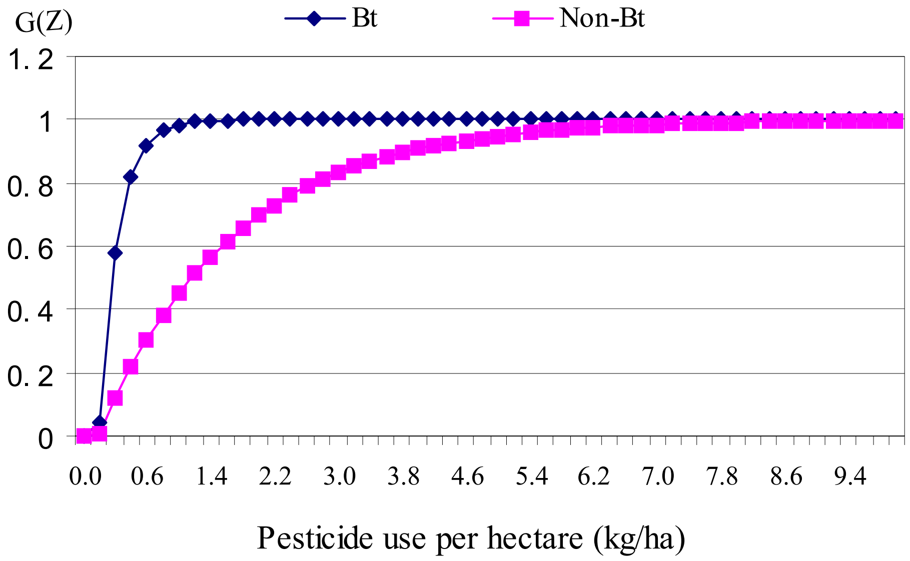
Table 6.1 Two-stage least squares estimates of pesticide use and cotton yield based on Cobb-Douglas and damage abatement control production functions

	Amount of *pesticide use* (kg/ha)	**Cotton yield function, LnYield (kg/ha)**	
		Cobb-Douglas function	**Damage control function**
Perception of y*ield loss* (%):	0.135 (0.03)***		
Average pesticide *price* (yuan/kg)	–0.133 (0.03)***		
Farm size (ha)	–13.259 (3.38)***		
Household characteristics			
Age (years)	0.016 (0.07)	-0.033 (0.05)	-0.030 (0.06)
Education (years)	–1.302 (0.28)***	-0.005 (0.01)	-0.001 (0.01)
Village leader dummy	1.336 (2.25)	0.074 (0.04)*	0.073 (0.04)*
Bt cotton training dummy	–2.717 (1.49) *	0.032 (0.03)	0.029 (0.03)
Conventional inputs			
Labour input (Days/ha)		0.02 (0.04)	0.033 (0.04)
Fertiliser (kg/ha)		0.107 (0.02)***	0.126 (0.02)***
Other inputs (yuan/ha)		0.159 (0.01)***	0.160 (0.01)***
Coated seed dummy	–4.699 (1.71)***	0.061 (0.03)*	0.072 (0.03)**
Hybrid seed dummy	14.429 (2.17)***	0.058 (0.04)	0.047 (0.04)
Bt cotton *Variety dummy (Bt)*	–43.246 (4.03)***	0.083 (0.04)**	0.096 (0.03)***
Bt x T2000	12.60 (4.93)***		
Bt x T2001	10.33 (4.66)**		
Predicted *pesticide use* (kg/ha)		–0.021 (0.02)	
Damage control parameter estimates			
c (pesticide parameter)			0.593 (0.29)**
c_1 (*Bt* variety parameter)			3.540 (0.70)***

Notes: The figures in the parentheses are standard errors of estimates. ***, **, * denote significance at 1%, 5% and 10%, respectively. The model includes 7 dummy variables to control for specific impacts of location (4 provincial dummies), years (2000 and 2001), and disaster (flood vs. normal). The estimated coefficients for these dummy variables and intercept are not included for brevity.

In all cases, but especially for the case of non-*Bt* varieties, farmers are using pesticides far in excess of their optimal levels. For example, in the case of the estimates that use the damage control function, G(Z) approaches 1 after Z reaches 1 kg per hectare for *Bt* cotton and about 10 kg per hectare for non-*Bt* cotton (Figure 6.1), while actual uses of pesticides in *Bt* cotton range from 11.8 kg in 1999 to 32.9 kg in 2002, and from 60.7 kg in 1999 to 87.5 kg for non-*Bt* cotton. These results illustrate that pesticides are being over used by both *Bt* and non-*Bt* cotton producers.

Figure 6.1 The exponential damage abatement function, *G(Z)*, for *Bt* and non-*Bt* cotton



6.4.2 Pesticide use

The results of the pesticide use equation demonstrate that the first stage of our model generally performed well in explaining pesticide use (Table 6.1, column 1). OLS versions of the same model (not shown) indicate that the model has a relatively high explanatory power, with an adjusted R-squared value of 0.57, a level that is reasonable for cross-sectional household data. The results of the alternative functional forms (also not shown) demonstrate that the results are robust, as are most of the results for different versions of the model using alternative specifications for the dependent variable. Most of the signs of the estimated coefficients of the control variables are as expected.

Most importantly, the regression analysis illustrates the importance of *Bt* cotton in reducing pesticide use (Table 6.1, column 1). The negative and highly significant coefficient on the *Bt* cotton variable (*Bt*) means that *Bt* cotton farmers sharply reduced pesticide use when compared to non-*Bt* cotton farmers in 1999. *Ceteris paribus*, production using *Bt* cotton allowed farmers to reduce their pesticide use by 43.3 kilograms per hectare in 1999. Given that the mean pesticide use for non-*Bt* cotton producers was 60.7 kilograms per hectare in 1999 (Table 4.2), the adoption of *Bt* cotton is associated with a 71 per cent decrease in pesticide use. On the average, *Bt* cotton reduced pesticide use by 35.7 kg per hectare, or a reduction of 55 per cent of pesticide use in the entire sample between 1999 and 2001. Reduction rates vary among provinces (the results are not showed in Table 6.1), and ranged from 20–50 per cent in the Lower Reach of Yangtze River Basin to 70–80 per cent in the North China cotton production region. Based on the above findings, the hypothesis that *Bt* cotton reduces pesticide use (hypothesis 4) is fully accepted.

The parameters (b_{2000} and b_{2001}) for $Bt\ t_{2000}$ and $Bt\ t_{2001}$ are positive (12.6 and 10.33, Table 6.1, column 1) and statistically significant. However, an additional test on the difference between b_{2000} and b_{2001} shows that this difference is not statistically significant. Thus, we need more information to conclusively determine the outcome for hypothesis 5 regarding the development of resistance to the *Bt* gene by the cotton bollworm over time. While our data do show an increase in pesticide use in *Bt* cotton production in 2000 over 1999, it is not possible to definitively say why the 2000 increased pesticide use occurred based on this test, since the 2001 pesticide use was lower than that in 2000 for *Bt* cotton production.

There are several possibilities. One explanation could be that higher pesticide use was due to differences in naturally occurring fluctuations in pest populations; thus, the effect 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, a practice that could reduce the *Bt* protection effectiveness since saved seeds are of lower quality. The increased use of pesticides could also be due to the significantly greater plantings of *Bt* cotton varieties adopted in 2000 and 2001 over 1999. Some of these later varieties were generated by local institutes and were inferior to major varieties generated earlier by CAAS and Monsanto. It could also be that bollworms are beginning to develop resistance. However, there is evidence that 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 is available, they had not found any evidence of bollworm resistance to *Bt* cotton (Wu 2002).

Results presented in Table 6.1 also show a statistically significant parameter estimate, with large magnitude, corresponding to pesticide use associated with farmers' perceptions of yield loss due to pest attacks. In other words, when farmers expect to incur large yield losses from cotton bollworms, they spray more.

6.5 China and other developing countries

Many critics of biotechnology have argued that the benefits from *Bt* cotton, that have been shared by over 4 million Chinese small farmers, cannot be realised 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 fieldwork, we believe that most of China's farmers make their own decisions regarding crop plantings and technology use. Accordingly, China's farmers are like those of other developing 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 the 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 pre-testing our questionnaire we explicitly asked farmers in the 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 gone entirely. Since then, the market for cotton has been further liberalised and farmers face even less pressure for cotton production–in fact in recent years the government has been trying to discourage farmers from expanding cotton production with little or no success.

Moreover, we found no evidence of pressure to buy *Bt* cotton. Indeed China's governmental agencies have been providing conflicting messages about *Bt* cotton. For example, both commercialised government and private seed companies encouraged farmers to buy *Bt* cotton seed. Concurrently however, Plant Protection Stations and government-owned pesticide companies tried to discourage farmers from growing *Bt* cotton in order to sell more pesticides.

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

The main difference from other developing countries, however, is China's public sector's role in developing genetically modified (GM) technology. A large share of the *Bt* cotton varieties that Chinese farmers cultivate was developed by scientists working in public research institutes and sold by government seed companies. Political support from these scientists to allow commercialisation of GM technology is one of the reasons that China approved commercialisation of GM crops earlier than most other developing countries (Paarlberg 2000). In addition the competition between local government firms and foreign firms in providing *Bt* cotton varieties is undoubtedly one of the reasons that the prices of Chinese GM cotton seed is so low.

7 Conclusions

The use of *Bt* cotton is spreading very rapidly in China pulled by farmers' demand for this technology. By 2001, about 5 million farmers adopted *Bt* cotton, accounting for nearly 50 per cent of cotton production in China. This technology reduces cotton farmers' use of pesticides, and subsequently reduces their exposure to pesticides. Farmers have been able to increase their yield per hectare, reduce pesticide use and costs, and reduce the number of pesticide poisonings.

Econometric results from this research show that the production *Bt* cotton has positive crop yield impacts, shifting the crop yield frontier by nearly 10 percent. *Bt* cotton also effectively reduces yield loss through the abated damage, whereby the damage could be completely abated when 2–3 kg of pesticide per hectare is used on *Bt* cotton fields compared to nearly 10 kg of pesticide per hectare for non-*Bt* cotton. Thus, most importantly, the regression analysis illustrates the importance of *Bt* cotton in reducing aggregate pesticide use. On the other hand, we also find that the benefits of spreading *Bt* cotton decline as it moves from Hebei, Shandong and Henan to Jiansu. Recent government decision to commercialise *Bt* cotton in some part of Xingjiang should be re-accessed as the inset is much less serious than that in North China Plain. In regards to pest resistance, the test on the hypothesis of bollworm resistance to *Bt* cotton over time requires further research.

The damage control function also shows a significant overuse of pesticides by cotton farmers. Although a discussion of why farmers overuse pesticides is beyond the scope of this article, it is clear that such behavior is systematic and even exists when farmers use *Bt* cotton varieties. One thought is that farmers may be acting on poor information given from pest control station personnel and other players in the pesticide market. In fact, such a hypothesis would be consistent with the findings of work on China's reform-era extension system in general. Other explanations include farmers' risk consideration, pesticide price policies, and pest control knowledge.

In terms of policies, our findings suggest that the government should continue to invest *Bt* cotton and other biotechnology. And meantime, the important caveat is that government investments in regulation of biotechnology will have to be increased to ensure that widespread use of *Bt* does not lead to the rapid development of pest resistance.

The other implication of these findings is that the government could play a greater role in reducing pesticide use through information, extension related training, pesticide price and marketing policies. A combination of *Bt* cotton and integrated pest management activities would make *Bt* cotton even more beneficial to Chinese farmers.

The last part of this article argues that China is similar to other developing countries with respect to farmers' decisions to adopt *Bt* cotton based on their assessment of costs and benefits. Chinese farmers find growing *Bt* cotton 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 similar bollworm pressures and bollworms have become resistant to many common pesticides. In these cases, farmers are likely to benefit greatly from this technology.

The other lesson from China is the importance of local research on biotechnology. The fact that *Bt* cotton was developed by government researchers concurrently with its introduction into China by international companies, clearly made *Bt* cotton more palatable to the government and ensured that there was a strong lobby in favor of this technology.

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