Plant biotechnology in China: public investments and impacts on farmers

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Abstract
This article provides an overview of China' plant biotechnology development and its impacts on farmers. Our study shows that while Chinese policymakers have considered agricultural biotechnology as a strategically significant tool for improving national food security and raising agricultural productivity, they have been hesitant to approve the commercialisation of new genetically modified (GM) crops since the late 1990s. China now has several GM plant species such as rice, maize and soybean that are in the pipeline for commercialisation, but except for Bt cotton none have been approved for commercial release since 1997. In 2003, more than 5 million farmers adopted Bt cotton and nearly 60 percent of cotton area was planted with Bt cotton. Our survey data on yields and econometric analyses indicate that the adoption of Bt cotton increased output per hectare by nearly 10 percent and reduced pesticide use by 35 kg (or about 60 percent), which significantly improved the income of small farmers. We also provide evidence that farmers have less health problems because of reduced pesticide use. More importantly, our most recent survey shows that the performance of GM rice in the pre-production stage is impressive. Insect and disease resistant GM rice can reduce pesticide use per hectare by 17 kg (or nearly 80 percent). Our survey also provided evidence of a slight increase of yield from GM rice production. We conclude that plant biotechnology will significantly boost China's agricultural productivity and there are lessons for other developing countries in their experience.

Media summary
China is developing the largest public plant biotechnology sector in the developing countries. More than 5 million small farmers have benefited significantly from Bt cotton production. Future gains from GM rice will be substantial.

Key Words
Biotechnology, Bt cotton, GM rice, economic impacts, policy, China

Introduction
A survey of China's plant biotechnologists by the authors in 2000 shows that China is developing the largest plant biotechnology capacity outside of North America (Huang et al., 2002b). In 1997 when the National GMO Biosafety Committee was established, the Committee immediately approved 38 cases of field trials, environmental releases, and commercialisation, which covered 12 GM crops. Among them GM cotton, tomato, and petunia were approved for commercialisation in certain locations (Huang *et al*. 2001a).[1] A number of earlier studies such concluded that China was adopting a promotional policy to embrace the benefits of agricultural biotechnologies (Chen, 2000; Huang *et al*., 2001b). Suddenly, China became one of the leading countries in the world's biotechnology.

However, the above perceptions on China's position on agricultural biotechnology lasted for only a few years. China's State Council decreed a new rule of Regulation on Safety Administration of Agricultural GMOs in May 2001 and the Ministry of Agriculture (MOA) issued detailed regulations on the biosafety management, trade and labelling of GM farm products in early 2002. As a result, China received more criticism than support from both proponents and critics of biotechnology. Biotechnologists and industry criticised China's new regulations as being too restrictive to provide a favourable environment for biotechnology development and called the period after 1999 the Winter of Biotechnology". Meanwhile Green Peace and environmental agencies continuously warned China about the potential risks associated

[1] GM sweet pepper resistant to diseases was approved for commercialization in 1998.

with GMOs. The United States government accused Beijing of using the new rules to hinder imports and protect Chinese soybean farmers. The pressure has also been raised from China's export businesses (Huang and Wang, 2003). Critics of China's financial and institutional ability to label its GM farm products for domestic markets are also growing. Media even claimed that China has reversed its formerly enthusiastic embrace of biotechnology and imposed extra restrictions on both domestic and imported varieties of GM crops.[2]

After a 15-year nationwide promotion of agricultural biotechnology in China, current policy debates seem confusing to many observers. The decision makers are looking for advice on whether China should continue to advance its biotechnology and commercialise its GM foods such as rice, maize and soybean. The objectives of this paper are to review the status of China's policy on agricultural biotechnology research and commercialisation and to gain a better understand of the impacts of agricultural biotechnology on farmers. In order to achieve these objectives, the paper is organized as follows. The next section provides an overview of China's agricultural biotechnology development policies. In this section, we show that the growth of public investment in agricultural biotechnology has accelerated despite a lack of new GM crop approvals for commercialisation since the late 1990s. The third section examines the impacts of Bt cotton on farmers, which are based on our three-year surveys of 1056 cotton producers in five major cotton production provinces. The results show that the adoption of Bt cotton has significantly reduced pesticide use, raised cotton yield, and improved the income of small farmers. The small cotton farmers also benefited from reduced health problems because of reduced pesticide use. The fourth section examines the performance of GM rice in the pre-production stage at farm level in 2002-2003. Our preliminary analysis shows that the commercialisation of GM rice will lead to substantial economic gains. The reduction of pesticide use is impressive. Insect and disease resistant GM rice can reduce pesticide use per hectare by about 17 kg. Our survey also provided evidence of a yield increase from GM rice production. The final section provides concluding remarks.

Agricultural Biotechnology Development and Policy

Agricultural biotechnology is one of the prioritised areas that received the highest attention in China. Tracking back to the early 1980s when China prepared to initiate the national biotechnology program, the goals of biotechnology development have been defined in several dimensions. From the point of view of users of biotechnology, the government defined the goals of biotechnology development as improving the nation's food security, promoting sustainable agricultural development, increasing farmer income, improving the environment and human health, and raising its competitive positions in international agricultural markets along with other public agricultural development programs. From the point of view of the technology itself, the most frequent statement of the development goal of biotechnology in China is to create a modern, market responsive, and internationally competitive biotechnology research and development system (MOST, 1990 and 2000).

To meet the above goals, the national plan and strategy to modernize agricultural biotechnology was composed of several main measures. These include measures to set up a comprehensive publically financed research system, investment to enhance innovative capacity, and institutions and regulations to ensure the healthy development of agricultural biotechnology which contributes to human welfare (MOST, 2000).

National Agricultural Biotechnology Research Institutions

An ambitious scheme to promote biotechnology research was started in the beginning of "Seventh Five-Year Plan" (1986-1990) when the first comprehensive National Biotechnology Development Policy Outline was issued. Under this Outline, a number of high profile technology programs have been launched after the middle 1980s. Some of the most significant programs include "863 High-Tech Plan", "973 Plan", the Initiative of National Key Laboratories on Biotechnology, Special Foundation for Transgenic Plants Research and Commercialisation (SFTPRC), Key Science Engineering Program,

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[2] See recent report in Washington Post (China's New Economy Begins on the Farm, Growers Bear Burden of Being First As Trade Brings Opportunity, Risk, by Peter Goodman, Page A01, Sept. 25, 2002). New York Time (The Science and Politics of Super Rice, by Joseph Kahn, October 22, 2002). China Daily front page article (GM Rules Don't Block Imported Products, by Xing Zhigang, July 11, 2002).

Special Foundation for High-Tech Industrialization (or Commercialisation), Bridge Plan, and so on (Huang and Wang, 2003).

The "863" Plan, also called National High-Tech Research and Development Plan, was approved in March 1986 as a result of the recommendation from four leading scientists in China. The "863" Plan supports a large number of applied as well as basic research programs. Biotechnology is one of sevensupporting areas under the Plan. The National Basic Sciences Initiative, also named "973" Plan, another high-tech research plan, was initiated in March 1997. The plan is complementary to "863' and many other national initiatives on high-tech development, as it supports exclusively basic research. Life science, with biotechnology as priority, constitutes one of the key programs under the plan. In order to strengthen the national research and industrialization of China's agricultural biotechnology, the Ministry of Sciences and Technology (MOST) initiated a new program, SFTPRC, in 1999. This is a unique Foundation to promote both research and commercialisation of transgenic plants.

Meantime, MOST and SDPC (the State Development and Planning Commission) jointly led, the Key Science Engineering Program (KSEP), a national program to promote the fundamental construction for research, and initiated a biotechnology sub-program in the late 1990s. Moreover, the State Council passed a new Agricultural S&T Development Compendium in 2001. The Compendium re-emphasises the importance of agricultural biotechnology in improving the nation's agricultural productivity, food security, and farmers' income, which has led to a new decision to further raise research budgets for biotechnology development.

By 2001 there were about 150 laboratories at national and local level located in more than 50 research institutes and universities across the country working on agricultural (plant and animal) biotechnology. Over the last two decades, China established more than 30 National Key Laboratories (NKL). Among these NKLs, twelve are exclusively working on and three have major activities in agricultural biotechnology (Huang *et al*., 2001b). Besides NKLs, there are numerous Key Biotechnology Laboratories and programs under various Ministries and local provinces.

Human Research Capacity Building and Investment

The number of plant biotechnology researchers more than tripled in the past two decades.[3] We estimate that there were about 2700 researchers (including supporting staff) working in plant biotechnology in 2003 (Table 1). If we include biotechnology from the animal sector, the number of researchers in agricultural biotechnology may be more than 4000, which probably is one of the largest in the world. Moreover, a remarkable improvement has also occurred in human capacity to conduct biotechnology research. Among professional staff, the share of researchers with PhD degrees increased from two percent in 1986 to more than 20 percent in 2000 (Huang *et al*., 2001b). This share is expected to keep rising in the future as the capacity to run PhD programs in biotechnology has been strengthened.

Agricultural biotechnology research in China is predominantly financed and undertaken by the public sector. The growth in agricultural biotechnology research investment in the public sector has been substantial. The estimated investment in plant biotechnology research was only US$4.2 million in 1986 when China formally started its "863 Plan" (Table 1). The investment grew to US$8.3 million in 1990, US$ 10.5 million in 1995, and US$ 38.9 million in 2000; the increase in 1995-2000 represents an annual growth rate of about 30 percent. The investment in plant biotechnology research continued to grow in the first few years of the 21st century. The spending in plant biotechnology reached US$55.9 million in 2003, about 44 percent higher than that in 2000 (Table 1). Nearly all investment in biotechnology in China is from government sources. Public investment accounted for 94 percent of the total plant biotechnology budget in 1999 (Huang *et al*., 2001), the ratio was about 98 percent in 2003.

Agricultural Biotechnology Development

Significant progress has been achieved in both applied and basic research. According to a nationwide survey conducted by MOA in 1996, Chinese scientists had investigated the use of more than 190 genes

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[3] This is based on our primary survey of 29 research institutes in plant biotechnology in 2000, extensive interviews with the ministries and research institutes in 2002, and our most recent research institute survey in 2004.

,transferred to over 100 organisms (103 genes used in 47 plants, 32 genes used in 22 animals, 56 genes used in 31 species of micro-organisms). These figures have been further expanded after 1996 (Cheng and Peng, 2002). By 2001, there were over 60 plant species under research and 121 genes used for transformation (Peng, 2002). The list of GM crops in trials is also impressive and differs from those being worked on in other countries. Recently, Chinese researchers also announced the successful sequencing of the rice genome in 2002 (Yu et al, Science, 2002). They have produced a draft sequence of the rice genome for the most widely cultivated subspecies in China, *Oryza sativa* L. ssp. *indica*, by whole-genome shotgun sequencing.

Rice, cotton, wheat, maize, soybean, potato, and rapeseed are priority crops for biotechnology research funding. Priority traits include those related to insect and disease resistance, stress tolerance, and quality improvement. Pest resistance traits have top priority. Recently, quality improvement traits have been included as priority traits in response to increased market demand for quality foods. In addition, stress tolerance traits — especially resistance to drought — are gaining attention, particularly with the growing concern over water shortages in Northern China.

Newer research focuses on the isolation and cloning of new disease and insect-resistance genes, including genes conferring resistance to cotton bollworm (Bt, CpTI and others), rice stem borer (Bt), rice bacterial blight (Xa22 and Xa24), rice plant hopper, wheat powdery mildew (Pm20), wheat yellow mosaic virus, and potato bacterial wilt (cecropin B) (MOA, 1999; NCBED, 2000). These genes have been applied in plant genetic engineering since the late 1990s. Significant progress has also been made in the functional genomics of Arabidopsis and in plant bioreactors, especially in utilizing transgenic plants to produce oral vaccines (BRI, 2000). By the end of 2001, GM plants from 13 plant species and more than 50 genes were approved for field trial, environmental release, and commercialization. Thirty-six recombinant microorganism species and 51 strains have been used in research with 89 genes for insect and disease resistance or nitrogen fixation (Huang and Wang, 2003).

Bt cotton is one of the most often cited examples of the progress of agricultural biotechnology in China. In addition, other transgenic plants with resistance to insects, disease or herbicides, or plants with improved quality have been approved for field release and some of them are nearly ready for commercialization. These include transgenic cotton lines resistant to fungal disease, rice resistant to rice stem borer or bacterial blight, diseases and herbicide, wheat resistant to barley yellow dwarf virus (Cheng et al., 1997), maize resistant to insects and with improved quality (Zhang, et al., 1999), poplar tree resistant to Gympsy moth, soybeans resistant to herbicides, potato resistant to bacterial disease or Colorado beetle, among others (MOA, 1999; NCBED, 2000; Li, 2000).

Progress in biotechnology has also been made in recombinant microorganisms such as soybean nodule bacteria, nitrogen-fixing bacteria for rice and corn, and phytase from recombinant yeasts for feed additives (Huang , 2002). GM nitrogen-fixing bacteria and phytase-producing yeast have been commercialised since 1999. In animals, transgenic pigs and carp have been produced since 1997 (NCBED, 2000).

Commercialization of Agricultural Biotechnology

From 1997-2003, the National Agricultural Biosafety Committee received a total of 1044 (821) cases of GMOs (GM plants) for field trials, environmental release, pre-production, and commercialization, of which 777 (585) were approved. Eighteen transgenic cotton varieties generated by Chinese institutions and five varieties from Monsanto with resistance to bollworm had been approved for commercialization in China in 1997-2002. While several GM varieties of tomato, sweet pepper, chili pepper and petunia have also been approved for commercialization since 1997, the areas planted under these four crops are very small.

Bt cotton accounted for more than half of China’s cotton area after 2002. Table 2 presents our most updated estimates of Bt cotton sown areas in China in 1997-2003. After the Bt cotton variety was approved for commercialization in 1997, the total area under Bt cotton increased to 0.65 million hectares in 1999, more than 2 million hectares in 2001 and reached 2.8 million hectares in 2003. Although this accounted for only about 4 percent of the total global area of GM crops in China in 2003, we estimate that more than 5 million farmers planted Bt cotton, as the average farm size is only about 0.5 hectare with several crops.

After several years of environmental release of GM rice, China approved several varieties of GM rice for pre-production testing in 2003. The push for commercialization of GM rice from the leading scientists in China has been growing. The national leaders are taking seriously the consideration of the final approval of GM rice commercialization.

Impacts of *Bt* Cotton

Data and Surveys

To assess the impact of Bt cotton 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 total number of farmers in our 1999 survey was 283. In 2000, we included two additional counties in Henan province, the total number of farmers interviewed increased to 407. In 2001, we added Anhui and Jiangsu provinces because the use of *Bt* cotton had spread further south. However, in our quest to compare the use of *Bt* and non-*Bt* cotton production, we had to drop some of the farmers previously surveyed in our 1999 and 2000 sampled villages in Hebei, Shangdong and Henan because they had fully adopted *Bt* cotton in 2001. Thus, the total number of farmers interviewed in 2001 was 366.

Impacts on Cotton Yield and Pesticide Application

Data in Table 3 show that *Bt* cotton variety yields were higher than those of non-*Bt* varieties. For example, in 2001 when comparing yields for all surveyed farms, yields of *Bt* varieties were about 10 percent higher. When other inputs, human capital variables, time- and location-specific variables, and other factors are accounted for (using econometric techniques), we found 9.6 percent yield increase (912 yuan revenue increase, 8.25 yuan = 1US$) was due to the adoption of *Bt* cotton in 1999-2001 (Pray *et al*., 2001, 2002; Huang, *et al*., 2002a, 2003a,2003b).

When comparing pesticide use on *Bt* cotton to that of non-*Bt* cotton (Table 3), our data demonstrate that growing *Bt* cotton varieties led to reduced pesticide usage. For the provinces that adopted *Bt* cotton first, Hebei and Shandong, 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, was the difference in pesticide use small between *Bt* and non-*Bt* cotton, only 7 kilograms per hectare.

Most importantly, after control for other factors' impacts, the regression analysis illustrates the importance of *Bt* cotton in reducing pesticide use (Huang *et al*., 2003b). On the average, *Bt* cotton reduced pesticide use by 35.7 kg (about 870 yuan) per hectare, or a reduction of 55 percent of pesticide use in the entire sample between 1999 and 2001. Reduction rates varied among provinces, and ranged from 20-50 percent in the Lower Reach of Yangtze River Basin to 70-80 percent in the North China cotton production region. While on average farmers paid additional 410 yuan per hectare due to higher Bt cotton seed price, the net income gains from Bt cotton production was 1378 yuan (166 US$) per hectare. Meantime, the cotton farmers also saved 41 days per hectare for reduced pesticide applications.

Impacts on Farmer Health and Environment

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. In the past, a large numbers of farmers became sick from pesticide applications each year (Huang *et al*., 2001c).

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. Huang et al. (2003a,2003b) and Pray et al. (2002) found that the percentages of reported poisoning of farmers were particularly high–22 percent and 29 percent for non-Bt cotton production farmers in the first two years. In contrast, between 5 and 8 percent of farmers who used only *Bt* cotton reported that they had become sick from spraying pesticides.

Using the differences in average pesticide use and the area planted to *Bt* cotton, a rough estimate of the decline in pesticide usage can be calculated. In 1999, the reduction in pesticide use was 22,000 tons, . while in 2003, due to increased area planted to *Bt* cotton, the reduction of pesticide use reached of 95,000 tons in China. 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.

Impacts of GM Rice

Data and Surveys

Transgenic hybrid and conventional Bt rice varieties, resistant to rice stem borer and leaf roller were approved for environmental release in 1997 and 1998 (Zhang *et al*., 1999). A transgenic rice variety that expresses resistance to rice plant hopper has been tested in field trials., The CpTi gene and the Bar gene were successfully introduced into rice through anther culture, providing resistance to rice stem borer and herbicide (NCBED, 2000). Transgenic rice with Xa21, Xa7 and CpTi genes, resistant to bacterial blight or rice blast also has been approved for environmental release since 1997 (NCBED, 2000). Significant progress has also been made with transgenic rice plants expressing drought and salinity tolerance genes, which has been in field trials since 1998. GM nitrogen fixing bacteria for rice have been approved for commercialization in 2000. Technically, several types of GM rice are ready for commercialization. However, commercial GM rice production has not yet been approved. Instead, China allowed the scientists to conduct a “Pre-production” trial at farm level, before GM rice is formally approved for commercialization. This provides us with a unique opportunity to evaluate the impacts of GM rice.

The analysis presented in this section is based on two primary rice producer surveys in one village in Fujian province and seven villages in five counties in Hubei province where the pre-production of GM rice were recently approved . Two major GM rice varieties covered in this study are II-Youming-86 (with CPTi gene, developed by Chinese Academy of Sciences and its collaborators) in Fujian and Xianyou-63 (with Bt gene, developed by Central China Agricultural University) in Hubei. The authors conducted the surveys in 2002 and 2003. These two years surveys include 178 rice producers or households (74 in 2002 and 104 in 2003) and 347 rice production plots (surveys were conducted at plot level with 123 plots planted with GM rice and 224 plots planted non-GM-rice). Among 74 households in 2002, 36 farmers planted non-GM rice only, 26 farmers planted both GM and non-GM rice varieties, and 12 farmers planted GM rice only. In 2003, 33 farmers planted non-GM rice only, 55 farmers planted both GM and non-GM rice varieties, and 16 farmers planted GM rice only.

Impacts on Rice Yield, Pesticide Application and Labor Input

The data provided in Table 4 show that GM rice provides a higher yield and lower pesticide use. For example, when comparing yields for all surveyed farms, GM rice varieties yielded about 8 percent more in 2002 and 1.5 percent more in 2003. When disaggregating the samples into varieties and locations, we found that the gains in yield are even larger. The reduction of pesticide is very obvious. In Hubei, the farmers who adopted GM rice applied less than 2 kg per pesticide hectare, while the pesticide use was 17.2 kg /ha in 2002 and 19.8 kg/ha in 2003 (Table 4). In Fujian, the decline in pesticide usage due to adopting GM rice was as high as 22.6 kg/ha in 2002 and 27.5 kg/ha in 2003.

Because the pesticide usage and yield may also be affected by other factors, evaluation of the true impacts of GM rice requires further analysis. We applied a regression analysis, which showed that GM rice reduced pesticide usage in our study areas by 17 kg/ha and yield increase was about 5-8 percent (Hu *et al*., 2004). The reductions of both labour inputs (17 days/ha) and farmers’ poisoning cases during pesticide applications with GM rice adoption are also evidenced in our study.

Concluding Remarks

Despite the growing debate worldwide on GM crops, China has developed agricultural biotechnology decisively since the mid-1980s. The growth of government investment in agricultural biotechnology research has been remarkable. China now has several GM crops that are in the pipeline for commercialization. The recent emphasis on developing drought resistant and other stress tolerant GM crops also suggests that biotechnological products are not only being geared at high-potential areas, as critics argue but also at the needs of poorer farmers.

Although China is still struggling with issues of environmental and consumer safety, many competing factors are putting pressures on policy makers to continue with the research and commercialization of transgenic crops. The demand of producers (for productivity-enhancing technology) and consumers (for cost savings), the current size and rate of increase of research investments, and past success in developing technologies suggest that products from China's plant biotechnology industry are likely to become widespread inside China in the near future.

The use of *Bt* cotton is spreading very rapidly in China pulled by farmers' demand for this technology. This technology as well as GM rice reduces farmers' use of pesticides, and subsequently reduces their exposure to pesticides. The technologies also increase crop yield per hectare.

In terms of policies, our findings suggest that the government should continue to invest in agricultural biotechnology and promote the commercialization of GM rice. And meantime, the important caveat is that government investments in regulation of biotechnology will have to be increased to ensure that widespread use of GM plants does not lead to the development of pest resistance and potential environmental risk (if there would be any) is minimized.

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. 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 favour of this technology.

Table 1. Estimated research staff and annual expenditure on plant biotechnology research in China, 1986-2003.

Year	Staff	Research expenditure		
		Million RMB at current price	Million RMB at 2000 price	Million US$
1986	740	14	38	4.2
1990	1067	40	68	8.3
1995	1447	88	87	10.5
2000	2128	322	322	38.9
2003	2690	462	463	55.9

Note: expenditures include both project grants and costs related to equipment and buildings. Sources: 2003 data are from our recent survey and the others are from Huang and Wang (2003).

Table 2. Bt cotton adoption in China, 1997-2003

Year	Cotton area (000ha)		Bt cotton share (%)
	Total	Bt cotton	
1997	4491	34	1
1998	4459	261	6
1999	3726	654	18
2000	4041	1216	30
2001	4810	2176	45
2002	4184	2201	53
2003	5021	2800	56

Source: Authors' survey.

Table 3. Pesticide application on and yield of *Bt* and non-*Bt* cotton in 1999-2001.

	Pesticide use (kg/ha)			Yield (kg/ha)		
	1999	2000	2001	1999	2000	2001
Hebei						
Bt	5.7	15.5	19.6	3197	3244	3510
Non-*Bt*	na	Na	na	Na	na	na
Shandong						
Bt	15.3	24.5	21.2	3472	3191	3842
Non-*Bt*	60.7	Na	na	3186	na	na
Henan						
Bt		18.0	15.2		2237	2811
Non-*Bt*		48.5	35.9		1901	2634
Anhui						
Bt			62.6			3380
Non-*Bt*			119.0			3151
Jiangsu						
Bt			41.0			4051
Non-*Bt*			47.9			3820

Note: Red spider mite was the most serious problem in Anhui and Jiangsu in 2001, while bollworm was less serious. Source: Huang et al., 2003a, 2003b.

Table 4. A summary of impacts of *Bt* cotton on pesticide use and yield based on the empirically estimated econometric models of pesticide application and cotton production functions.

	Pesticide use	Cotton yield change (%)
Bt over Non-*Bt* cotton	- 35 kg/ha	+ 9.6%

Note, detail models and estimation results can be found in Huang et al. (2003a), Huang and Wang (2003), and Huang et al (2002 and 2003b).

Table 5. Pesticide use and yield of GM and non-GM rice in sampled provinces, 2002-2003

	2002			2003		
	Sample plots (n)	Yield (kg/ha)	Pesticide (kg/ha)	Sample plots (n)	Yield (kg/ha)	Pesticide (kg/ha)
Hubei						
GM Xianyou-63	38	6968	1.6	78	5949	1.7
Non-GM Xianyou-63	23	5968	25.7	9	5779	21.3
Non-GM others	44	6950	12.7	109	5911	19.7
Fujian						
GM II-Youming-86	4	7313	6.8	3	8250	8.2
Non-GM II-Youming-86	8	7186	31.8	4	5670	31.9
Non-GM others	13	5294	27.9	14	6362	36.8
All samples						
GM:	42	7000	2.1	81	6034	2.0
Xianyou-63	38	6968	1.6	78	5949	1.7
II-Youming-86	4	7313	6.8	3	8250	8.2
Non-GM	88	6470	20.1	136	5945	21.9
Xianyou-63	23	5968	25.7	11	5785	24.6
II-Youming-86	8	7186	31.8	7	5970	27.3
Others	57	6573	16.2	118	5958	21.3

Note: Surveyed counties included Xiantao, Jiangxia, Huangpi, Jingmen, and Xiangyang of Hubei province, Shunchang of Fujian province.
Source: Authors' surveys.

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