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**Development, Policy and Impacts of Genetically Modified
Crops in China:
A Comprehensive Review of China's Agricultural
Biotechnology Sector**

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1. Introduction

When there are public debates about whether or not developing countries will be able to make use of modern biotechnology to improve the performance of their agricultural sectors and meet their national development goals, China is often cited as one of most successful developing countries (James, 2004; Paarlberg). This is not surprising given the impressive development of plant biotechnology and the record of adoption of genetically modified crops (GMOs) over the past 2 decades (Huang et al., 2002a and 2005a; Huang and Wang, 2003). In 1997 shortly after the National Genetically Modified Organisms Biosafety Committee (GMOBC) was established, the committee approved 46 applications of scientists requesting permission to conduct field trials, environmental release trials and commercialize GM crops. The initial round of commercialization permits covered 12 GM events.¹ By 2004, more than 1200 cases had been approved for trial and/or commercialization. Moreover, at least in the case of cotton, GM crops have been widely adopted by farmers; today Bt cotton accounts for about 65 percent of China's total cotton area. Several GM rice varieties are on the threshold of being commercialized.

Although previous studies have demonstrated the positive impact of plant biotechnology in boosting China's agricultural productivity, little is known about either the constraints (or enabling factors) that China as a nation that is seeking to use GMOs as a key part of its agricultural development strategy has encountered in the past or barriers that the nation may face in the future. There have been a number of studies primarily focused on the effect of Bt cotton on productivity (Pray et al., 2002; Huang et al., 2002b, 2003a and 2003b) and pesticide-related health status of farmers (Huang et al., 2002a and 2005a, Hossain et al., 2004; Pray et al., 2001). These studies have provided an example of the promise that biotechnology can holds for small farmers in China. A more recent study on GM rice further demonstrates the positive effect on productivity and health that GM crops can generate for poor, small farm households (Huang et al., 2005a).

In spite of these success stories, it is possible that had it not been for certain policy constraints or other barriers, China's plant biotechnology program may have produced even greater benefits. Somewhat surprisingly, given the importance of these issues with several notable exceptions, there has been little work on identifying the constraints to further development of plant biotechnology in China. The work of Keeley (2003), Huang and Wang (2003) and Huang et al. (2005) begin to investigate the policies and challenges of managing China's plant biotechnology sector.

¹ Among them 5 cases of cotton and 1 case of each tomato and petunia were approved for commercialization in 7 provinces (MOA, 2005). In the following year, GM sweet peppers were also approved for commercialization.

However, these studies mainly address the record of China's biotechnology research investment and only begin to provide preliminary evidence on the nation's biosafety regulations. Almost no one has written directly on the subject of whether or not China has or will face serious constraints in its past/future plant biotechnology research and investment program. To our knowledge no one has directly taken on the question that is perhaps even more interesting: what constraints are holding (or may continue to hold) China back from commercializing additional GM crops in the future.

The increasing complexity of China's economy, in particular, and society, in general is making the need to understand the policy and regulatory environment even more important. In addition, it is becoming imperative to understand the factors that can make the regulatory environment function effectively enough to ensure that China's plant biotechnology products are safe and well-managed. In recent years, opponents of biotechnology have begun to campaign actively against China's GM development. For example, Green Peace and other environmentalist groups claim that China does not pay enough attention to biosafety, the possible environmental consequences of GM crops or consumer concerns and food safety. One of the complaints of opponents of GMOs has made international headlines; it has been alleged that GM rice production from pre-production trials have been sold in many retail markets without approval. Some scholars have argued that the development of GM foods also have economic costs that have not been considered, such as the negative consequences on China's agricultural exports. Others are afraid that China's agricultural biotechnology program could be dominated by multinational life science corporations. Hence, when analyzing national policies it is important to consider a wide range of issues, an approach that has not been systematically addressed to date.

Besides issues that are specific to China itself, a study that helps scholars and policymakers understand the constraints facing the expansion of plant biotechnology is important since the case of China may provide relevant lessons for other developing countries. Specifically, the experience of China may aid other countries in making their own agricultural biotechnology sectors function more effectively and address some of the common institutional challenges that are associated with the development, extension and management of GMOs.

In meeting these broad goals, there are a number of issues that need to be examined. How China has developed its agricultural biotechnology programs? What are the major policies and institutions that have facilitated their development? What have been the social and economic impacts of GM crops? What are the institutional challenges that policymakers have and continue to face in their efforts to promote R&D, commercialize and regulate biotechnology GMOs? By addressing these questions as a set, we seek to describe the experiences and lessons of the first two decades of China agricultural biotechnology development and discuss what factors have in the past (and potentially in the future) affected China's biotechnology progress.

To meet this overall goal and address these issues, we seek to achieve four specific objectives. First, we want to gain a better understanding of the policies that have governed agricultural biotechnology research, commercialization and biosafety regulations. Second, we review the past progress and current status of China's agricultural biotechnology research, the record of commercialization and examine how its biosafety regulations have been implemented. Third, the paper identifies the social and economic impacts of the development of agricultural biotechnology. Finally, we examine some of the key, remaining institutional challenges for agricultural biotechnology R&D, commercial dissemination and biosafety regulations.

In order to achieve these objectives, the paper is organized as follows. The next section reviews the goals of China's biotechnology program, discusses the nation's strategy for meeting the goals and documents the successes the strategy has had in producing the biotechnology products that appear in China today and those that are becoming ready to be commercialized in the future. The following section reviews the socio-economic impacts of GM crops, focusing primarily on Bt cotton and GM rice. The fourth section describes the nation's plant biotechnology research and development programs and institutions and provides measures of the level of investment into agricultural biotechnology and the effect it has had on the human resources that are carrying out China's biotechnology R&D. The following two sections examine biosafety management and regulation and discuss the commercial dissemination of GM crops. In each section, a number of possible factors that are creating institutional constraints that are retarding the development of plant biotechnology R&D, commercialization and effective biosafety regulation are identified. The final section provides concluding remarks.

2. Agricultural Biotechnology Development and Policy

2.1 Development Goals and Strategies

Beginning in the early 1980s as China prepared to initiate its national biotechnology program, the stated goals of its efforts were multifaceted. The government defined its goals in terms of improving the nation's food security, promoting sustainable agricultural development, increasing farmer income, improving the environment and human health, and raising its competitive position in international agricultural markets. In terms of the biotechnology sector itself, the most frequently stated goal was to create a modern, market-responsive and internationally competitive biotechnology R&D program (MOST, 1990 and 2000; SSTC, 1990).

To meet these goals, the government's plan to modernize its agricultural biotechnology system included several key measures. At the heart of the strategy was the set of measures set up to establish a comprehensive public-financed research system (MOST, 2000; SDPC, 2003). The system was to be supported by investment to enhance the

research capacity (defined in both human and physical terms) of the national biotechnology scientific community. The government also knew it needed to create a series of institutions and set of regulations that could ensure the healthy and safe development of the technology that could contribute to directly to human welfare as well as would be able to stimulate the commercialization of biotechnology. In addition to support to government institutes, leaders also wanted to encourage support to the private sector in order to help promote the downstream commercialization of biotechnology products.

Although the discussion in this section has focused on the stated goals of China's biotechnology product, in the rest of the paper we will evaluate some of the practical aspects of the actions taken in the implementation of programs that sought to achieve these goals. While complicated and nuanced, overall our discussion shows that the efforts to implement the plans outcomes of the policies generally have been positive. Of course, in many areas, there also is room for improvement. In general, the suggestions for improvement of China's biotechnology development strategy include closer coordination among the players in the nation's biotechnology R&D, improvement, better enforcement of biosafety regulations, the promotion of reforms to the seed industry, and the changes to policies related to intellectual property rights (IPRs).

2.2 Agricultural GM Technology Development

According to a nationwide survey conducted by MOA in 1996, China's scientists have experimented with more than 190 genes that have been transferred to more than 100 types of organisms. Among the total, 103 genes have been used in 47 types of plants; 32 genes have been used in 22 species of animals; and 56 genes have been used in 31 microorganisms. Since 1996, the scope of China's biotechnology achievements has expanded (Cheng and Peng, 2002). By 2001 there were over 60 types of plants using 121 different genes in their transformation (Peng, 2002). Between 2001 and 2003, the number of transformations increased even faster. By 2003 China's regulators had approved 1044 applications for agricultural biosafety assessment. Of these, 704 were approved for field trial, environmental release and pre-production. Seventy three 73 applications for commercialization have been approved. Except for a brief period after 2000, the annual increase in the number of cases approved by China's biosafety system has been relatively high (Figure 1).

Among all of the various research efforts, *Bt* cotton is the most successful plant biotechnology story in China. Cotton is China's number one cash crop. In response to the emergence of a pesticide resistant bollworm population and rising use of pesticides in the late 1980s, China's scientists began to research and develop a insect-resistant GM cotton. Starting with a gene isolated from the bacteria, *Bacillus thuringiensis* (*Bt*), China's scientists transferred the modified *Bt* gene into a number of major cotton cultivars by the using a novel, Chinese scientist-developed "pollen-tube

pathway” method of transformation. Greenhouse testing began in the early 1990s. The first commercial use of Bt cotton was approved in 1997. At that time, four Bt cotton varieties from China’s own publicly-funded laboratories and one from Monsanto, a foreign life science company were approved.² The commercial release of Bt cotton triggered China’s initial experience with GM crops that covered a fairly wide area.

Beside cotton, one of the most important achievements of China’s scientists has been the effort to create GM rice. During the past several years, China’s rice biotechnology research program has generated a wide array of new technologies. Currently, the new technologies are at all stages of the R&D process. Since the beginning of research on many of these varieties in the late 1980s and early 1990s, different transgenic rice varieties have been through field and environmental release trials. Four varieties currently have reached pre-production trials. For example, transgenic rice with the Xa21 gene, which is supposed to create a rice plant that is resistant to bacterial blight, was approved for environmental release trials in 1997; one of the varieties entered pre-production trials in 2001. After several years of biosafety appraisals, in 2004 China’s Agricultural GMOBC recommended that the government allows its commercialization. China’s MOA reversed the approval on the basis that they required more detailed, biosafety information.

Beside the disease-resistant GM rice, China also has made significant progress in the development of several other types of GM rice. China’s scientists have developed GM rice varieties that express the Bt toxin in order to reduce the need to control rice stem borers and leaf rollers. A number of Bt rice varieties were approved for environmental release trials in 1997 and 1998 (Zhang et al, 1999, Huang et al., 2005a). Two of the Bt rice varieties—GM Xianyou 63 and Kemingdao—entered pre-production trials in 2001.³

During this same period, another group of scientists in China also succeeded in introducing a modified CpTI gene into rice. This product was approved for environmental release trials in 1999. After being introduced into a hybrid variety of rice, GM II-Youming 86, regulators allowed scientists to begin pre-production trials in 2001.⁴

Our interviews also found that although environmental release trials have not begun, greenhouse trials in China have been underway since 1998 for transgenic rice with herbicide tolerance. One of the main new technologies uses the Bar gene. There

² Monsanto has patents on several genes that are important in the production of transgenic plant varieties (henceforth, the Monsanto gene). The Monsanto genes are legitimately managed by two joint venture seed companies set up originally by Monsanto, Delta-Pinelands (DP) and a provincial seed company (Jidai in Hebei and Andai in Anhui—henceforth called Jidai for convenience).

³ The two Bt varieties are resistant to three stem borers in China—*Tryporyza incertulas* Walker, *Chilo suppressalis* Walker and *Cnaphalocrocis medinalis* Guenée.

⁴ The hybrid GM II Youming 86 contains the CPTI gene which provides resistance to six pests, the same pests that are targets of varieties containing Bt plus *Sesamia inferens* Walker, *Parndra guttata* Bremeret Grey and *Pelopidas mathias* Fabricius.

also have been reports that scientists are working on rice varieties that express drought and salinity tolerance in rice.

In addition, other transgenic plants with resistance to insects, disease and herbicides have been approved for field trials and some are nearly ready for commercialization. For example, China's scientific community has produced a number of cotton lines that are resistant to fungal disease (Cheng, He, and Chen 1997). There also have been breakthroughs in wheat varieties with resistance to barley yellow dwarf virus and maize varieties that are resistant to insects (Zhang et al., 1999). A number of smaller crops are being experimented with that have improved quality traits. For example, China's scientists are developing poplar trees resistant to Gypsy moth, soybeans resistant to herbicides and transgenic potato resistant to bacterial disease and Colorado beetles (MOA, 1999; NCBED, 2000; Li, 2000).

Progress in plant and animal biotechnology also has been made in a number of other areas. For example, China has produced several recombinant microorganisms, such as soybean nodule bacteria, nitrogen-fixing bacteria for rice and corn, and phytase, a product made from recombinant yeasts that can be used for feed additives (Huang Dafang, 2002). Genetic modified nitrogen-fixing bacteria and phytase have been commercialized since 1999. In terms of animals, transgenic pigs and carp have been produced since 1997 (NCBED, 2000). Recently, China's scientists also announced the successful sequencing of the rice genome in 2002 (Yu, et al., 2002).⁵

2.3 Research Priorities

A review of China's agricultural biotechnology policy documents and an examination of the actual budgetary expenditures during the past 20 years show that while GM technologies have been developed for more than 60 types of plants, administrators have given priority to a small subset of crops, in particular, rice, cotton, wheat, maize, soybean, potato and rapeseed (Table 1). In fact, as will be shown in this section, the priority of crops under that nation's biotechnology program is generally consistent with the relative importance of the crops in terms of sown area. There also is evidence that the development of biotechnologies is consistent with the demands of farmers and national strategic concerns.

China's program has above all worked on crops that account for a large share of China's sown area. For example, newer research focuses on the isolation and cloning of new disease and insect-resistance genes, including the new 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,

⁵ 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. 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.

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).

China also has focused on crops in which the potential gains may be highest. While other crops command larger sown areas, cotton, which covers 5 to 6 million hectares and accounts for 4% of total crop area, has been particularly affected by agronomic problems. Insect pest infestation, particularly from the cotton bollworm (*Helicoverpa armigera*), has been a major problem for cotton production in northern China. China's farmers initially combated these pests using pesticides. However, China's bollworms began developed resistance to most pesticides in the late 1980s and early 1990s. As pest pressures rose and pesticide began to lose their effectiveness, the use per hectare of pesticides by cotton farmers in China rose sharply. Farmers use more pesticide per hectare on cotton than on any other field crop (Huang et al., 2000). 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 producers purchased nearly US\$ 500 million in pesticides annually (Huang et al., 2003b).

Perhaps because the government and farmers are concerned with production and marketing efficiency and stability, research administrators have given priority to insect and disease resistance, stress tolerance and quality improvement (Table 1). Above all, pest resistance has had top priority during the past two decades. Recently, however, scientists have begun to target quality improvement in response to increased market demand for quality foods. In response to growing concern over water shortages in northern China, stress tolerance—particularly resistance to drought—is gaining attention. Although no stress tolerant GM crop has been commercialized, the budget allocated to stress tolerance has been increasing and recently reached as much as the budget allocated to insect or disease traits (personal communications with MOST officials).⁶

Most interestingly, the crops that have received the highest priority also are the ones that are produced by relatively poor farmers (Huang, Li and Rozelle, 2003). In the cropping sector, poorer farmers have a greater propensity to produce staple commodities, such as food and feed grains, oilseeds and fiber crops.⁷ For example, rice is the most important food crop in China's agricultural economy. During the last three decades rice sown area has accounted for about 27 to 29 percent of total grain

⁶ The slower progress of stress tolerant varieties should not be surprising or a sign of failure. Stress tolerance has a more complicated mechanism that involves many metabolic pathways between the plant and its environment.

⁷ In contrast, farmers in regions with higher incomes have tended to produce more vegetables, fruit and other high-valued crops.

sown area (or about 20 percent of the nation's total crop area. Rice production accounts for from between 41 to 45 percent of total grain production (NSBC, 2003).

3. Socio-economic Impacts of GM Crops

Despite growing evidence that GM crops in developed countries, such as the US, reduce use of insecticides, decrease production costs and increase yields (Perlak, et al., 2001), critics of biotechnology often express doubt about its usefulness for small farmers in developing countries. For example, 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, implying that it can not be helping farmers. The validity of such statements are important since GM crops have begun to be used in an increasingly large number of developing countries, including China (Pray et al., 2001; Huang et al., 2002a), India (Qaim and Zilberman, 2001); South Africa (Ismael et al., 2001) and Mexico (Traxler et al., 2001).

This section seeks to summarize the available evidence of the impacts of GM crops on farmers in China.⁸ Because of the availability of data, we focus mainly on the cases of *Bt* cotton and insect-resistant GM rice. The impacts are divided into farm level and economy-wide impacts. The evidence on the effects of *Bt* cotton at the farm level is based on three years of farm-level surveys that we conducted in five of northern China's main production provinces (Pray, et al., 2001 and 2002; Huang, et al., 2002a, 2002b, 2003a and 2003b). The information on the impact of insect-resistant GM rice on producers is from our recent survey of insect-resist GM rice that are participating in the pre-production trials (Huang et al., 2005a). The economy-wide impacts are simulated using Global Trade Analysis Program (GTAP) and are reported fully in Huang et al. (2004).

3.1 Impacts of Bt Cotton at Farm Level

According to estimates based on our best estimates which use information from government sources and interviews with commercial firms, the area under *Bt* cotton has risen rapidly between 1997 and 2004 (Table 2). *Bt* cotton varieties were approved initially for commercialization in 1997. After rising from relatively low levels in the late 1990s, total sown area increased to 3.7 million hectares in 2004. Nearly two-thirds of China's cotton area was planted to *Bt* cotton. Although only about 5 percent of the world's GM area is in China, it almost certainly accounts for a much larger share of farmers that use GM crops. In 2004 we estimate that nearly 7 million Chinese farmers planted *Bt* cotton. The average farm size of the typical GM rice farmer is only around 0.5 hectares, and of that, only part of the area is planted to cotton as farmers tend to be diversified.

⁸ This section is mainly based on Huang et al. (2002a, 2002b, 2003a, 2003b, 2004, and 2005a) and Pray et al. (2001 and 2002). Different papers reflect the results from different years of surveys and crops (e.g., *Bt* cotton and GM rice).

To assess the effect of biotechnology on farmer production and income in China we conducted a series of surveys in 1999 (2 provinces), 2000 (3 provinces), and 2001 (5 provinces). In each successive year, we increased the number of provinces surveyed as the use of *Bt* cotton spread throughout China. The total number of farmers in our samples was 283 in 1999, 407 in 2000, and 366 in 2001. All farmers planted either *Bt*, non-*Bt* cotton or both. The sample households were randomly selected.

Descriptive analysis

Contrary to statements made in the literature (e.g., GRAIN, 2001), our data show clearly that *Bt* cotton variety yields are higher than those of non-*Bt* varieties (Table 3). For example, in 2001 when comparing yields for all of surveyed farms, *Bt* varieties were about 10% higher. Perhaps more importantly, and perhaps reflecting better farming practices by farmers over time, yield effects became more prominent in provinces that used *Bt* cotton for longer periods of time.

The pesticide reduction effects of *Bt* cotton are even greater than the yield effects (Table 4). In provinces that adopted *Bt* cotton in early years, Hebei and Shandong Provinces, farmers used substantially less pesticide on *Bt* cotton than on non-*Bt* cotton. For example, Hebei and Shandong *Bt* cotton farmers in 1999 used less than 20 percent of the pesticide volume on their cotton as compared to those cultivating non *Bt* cotton. The effect in provinces where *Bt* cotton was more recently introduced commercially, Henan and Anhui Provinces, the mean application of pesticides on *Bt* cotton also was reduced significantly—although in percentage reduction terms, the decrease was marginally less. Only in Jiangsu—the province in which adoption occurred latest and in a location in which red spider mites are the main pest rather than bollworms (Hsu and Gale, 2001)—was the difference in pesticide use relatively small between *Bt* and non-*Bt* cotton, only 7 kilograms per hectare. The pattern, then, is clear—there is a large productivity effect in the initial adopting provinces; and a significant, though smaller effect in provinces as they move increasingly away from the regions in which bollworms have historically been the major pest—Hebei and Shandong.

When looking at pesticide use per hectare on *Bt* cotton over time, the results are mixed (Table 4). In Hebei, 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. In Henan, pesticide use per hectare declined in 2001 over 2000. Although more precise assessment of the changes in pesticide use on *Bt* cotton over time is needed, at the very least there is not any evident findings that suggest the widespread use of *Bt* cotton is leading (at least until now) to a build up of resistance by the pest population to the *Bt* toxin.

The health aspects for producers that use new technologies also are important to consider. The health impacts are particularly important in China since pesticides are

primarily applied with small back-pack sprayers that are either hand-pumped or have a small engine. Farmers also typically do not use any protective clothing or breathing apparatuses. Hence, applying pesticides is a hazardous task. In many cases—in fact, arguably in most cases—farmers end up completely covered with overspray from the pesticides. Such practices—especially when coupled with rising pesticide use by farmers—have been linked with increasing numbers of farmers becoming sick from pesticide applications (Huang et al., 2001).

According to our data, by reducing the use of pesticides *Bt* cotton also has reduced the number of farmers who are poisoned annually by pesticides (Table 5).⁹ The data show this by comparing the incidences of farmers reporting becoming sick after using pesticides among farmers that fall into one of three categories: group 1—those farmers that exclusively use non-*Bt* cotton varieties; group 2—those that use both *Bt* and non-*Bt* varieties; and group 3—those that cultivate only *Bt* cotton varieties. When comparing group 1 (those that did not use *Bt* varieties) to farmers in groups 2 and 3, it is clear that a higher percentage of farmers planting only non-*Bt* cotton reported higher incidences of poisoning in each year of the sample—1999, 2000 and 2001. The percentages were particularly high—22% and 29% in the first two years. In contrast, the share of group 3 farmers that reported that they had become sick from spraying pesticides fell was only 5 to 8 percent.¹⁰

Econometric Analysis

In order to control for a number of factors that may be simultaneously affecting yields and pesticide use of farmers that produce *Bt* and non-*Bt* cotton (which are not held constant in the descriptive analysis), we use regression analysis to better isolate the effects. A 3-equation system of pesticide use and crop yield is used to evaluate the impacts of *Bt* cotton at farm level. To study the effect of *Bt* cotton on crop yields, we utilize a damage abatement production approach developed by Headley (1968) and Lichtenberg and Zilberman (1986).¹¹ Instrumental variables were used to estimate the pesticide use because of concerns of endogeneity. Because of their frequent use in the literature, we also report the results of our analysis that use a Cobb-Douglas production functional form (although the results are robust to functional form). Details of our

⁹ To assess the effects on farmers' health, enumerators asked households about how the use of pesticides affected their health during, or immediately after, the time that they applied pesticides. Specifically, the questionnaire asked the farmers, "During or after spraying for pesticides on your farm, did you suffer from any of the following symptoms: headaches, nausea, skin irritation, digestive discomfort or other problems?" If the respondent answered "yes," a follow-up question was asked: "After beginning to feel poorly, did you take any one of the following actions: 1) visit a doctor; 2) go home and recover at home; 3) take some other explicit action to mitigate the symptoms?" If the respondent answered "yes" to both of the questions, it was recorded as a case of pesticide-induced illness. The same method was applied in our GM rice study presented below.

¹⁰ Regression analysis supports these descriptive statistics on the impact of *Bt* cotton on farmer health (Hossain et al., 2004).

¹¹ Cobb-Douglas production function approach was also estimated to check the robust of the results and effective of using damage abatement production function.

modeling approach and the econometric estimation strategy can be found in Huang et al. (2002b) and Huang et al. (2003a).

The results of our multivariate analysis are largely supportive of the descriptive results in most dimensions. For example, the econometric analysis finds that *Bt* varieties raise cotton yields, even though yields are not affected by rising pesticide use (Table 6, column 2). The descriptive statistics presented in Table 3 show that yields for *Bt* cotton users are about 5 to 10 percent 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 by our econometric methods, *Bt* cotton users are shown to get from between 8.3 to 9.6 percent increase in yields (see the coefficient for the *Bt* cotton dummy variable in Table 6, columns 2 and 3). Hence, the multivariate analysis, like the descriptive results, demonstrates that *Bt* cotton raises yields to a level higher than they would have been without *Bt* adoption.¹²

The results of the pesticide use equation in our analysis demonstrate the importance of *Bt* cotton in reducing pesticide use (Tables 6, 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), the adoption of *Bt* cotton is associated with a 71% decrease in pesticide use. On the average, *Bt* cotton reduced pesticide use by 35.7 kg per hectare, or a reduction of 55% of pesticide use in the entire sample between 1999 and 2001. Reduction rates vary among provinces (the results are not showed in Table 6), and ranged from 20 to 50 percent in the Lower Reach of Yangtze River Basin to 70 to 80 percent in the North China cotton production region.

3.2 Impacts of Insect-resistant GM Rice at Farm Level

Although *Bt* cotton is the only GM crop that has been commercialized across widespread areas of China, our work on the farm-level effects of GM rice varieties that are still in the pre-commercialization stages of development show that similar effects of GM crops should be found when other crops are released.¹³ Several GM rice varieties have entered and passed greenhouse and environmental release trials; four varieties currently are in pre-production trials in the fields of farmers. Two of the varieties are the focus of our study (Huang et al., 2005a).¹⁴ The nature of China's preproduction trial system has

¹² 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, column 3); and 2) there is a statistically significant impact of pesticide use in reducing yield loss through the abated damage.

¹³ This sub-section is a summary of our recent paper published in Science (Huang et al., 2005a)

¹⁴ One variety, GM Xianyou 63, was created to be resistant to rice stemborer and leaf roller by inserting a Chinese-created *Bacillus thuringiensis* (*Bt*) gene. The other variety, GM II-Youming 86, also was created to be resistant to rice stemborers, but in this case the resistance was created by introducing a modified cowpea trypsin

facilitated the analysis of the effect of insect-resistant GM rice on farm households prior to commercialization. The pre-production trials of GM Xianyou 63 are being conducted by farmers in 7 villages in 5 counties in Hubei province. The trials for GM II-Youming 86 are being conducted in 1 village in Fujian province. In the pre-production villages households were randomly selected to participate in the study. All of the farmers that were randomly selected did participate and so all farmers in the sample villages can be divided into two groups—adopters and non-adopters. Each adopter was provided with a fixed amount of insect-resistant GM rice seed. For households with limited land size, the seed was enough to cover all of their plots (henceforth, full adopters). Others received only enough seed to cover part of their plots (partial adopters). Except for being provided insect-resistant GM rice seed, adopters cultivated the insect-resistant GM rice without the assistance of technicians.

The analysis presented in this paper is based on surveys of a randomly-selected subsample of households in the pre-production villages in 2002 and 2003. In total, 77 households (12 full adopters, 28 partial adopters, and 37 non adopters) in 2002 and 101 households (16 full adopters, 53 partial adopters, and 32 non-adopters) in 2003 were interviewed. In total, the survey obtained data from 347 rice production plots, 123 plots planted with the insect-resistant GM rice varieties and 224 plots planted with non-GM rice. More complete details of our sampling methods are available in Huang et al. (2005a).

Descriptive analysis

Like in the case of Bt cotton, our survey data show that there is a difference between yields of insect-resistant GM and non-GM varieties. According to the descriptive data, the mean of insect-resistant GM rice yields (6364 kg/ha) is higher than those of non-GM varieties (6151), although only by 3.5% (Table 7, row 5). ANOVA tests that differentiate among year, village and GM versus non-GM effects demonstrate that the effect is statistically significant.

Data from the surveys also demonstrate that the characteristics of rice producers using the insect-resistant GM rice and non-GM rice are nearly identical and the main difference between the households is in the level of pesticide use. For example, there is no statistical difference between the size of the farm/plot, the share of rice in the household's cropping pattern or the household head's age or education. In contrast, there is a large difference in the use of pesticides (Table 7, rows 1 to 4). GM rice farmers apply the same types of pesticides but apply them less than once per season (0.5 times) compared to 3.7 times per season by non-GM rice farmers. The difference in the levels of pesticide use on insect-resistant GM and non-GM rice is statistically significant. On a per hectare basis, the quantity of and expenditure on pesticides of non-GM rice production is 8-10 times higher than insect-resistant GM rice. Insect-resistant GM rice adopters spend only

inhibitor (CpTI) gene into rice. The insect-resistant GM varieties entered pre-production trials in 2001.

31 yuan per season per hectare on only 2.0 kilograms of pesticide for spraying for pests while non-adopters spend 243 yuan for 21.2 kilograms.

In the same way that research on Bt cotton adoption showed that the productivity effects of Bt cotton were supplemented by positive health effects, according to the analysis based on the survey data, similar effects occur within the sample rice-growing households. Among the sample farmers, there were no full adopters that reported being affected adversely by pesticide use in either 2002 or 2003 (Table 8). Of those that cultivated both insect-resistant GM and non-GM plots, 7.7 percent of households in 2002 and 10.9 percent of households in 2003 reported that their health was affected adversely by pesticide use; none, however, reported being affected after working on the sample GM plot. Of those that used only non-GM varieties, the health of 8.3 percent of households in 2002 and 3 percent in 2003 was affected adversely.

Econometric Analysis

To estimate the net effects of GM rice on pesticide use and rice yields, we follow the same approach used in Bt cotton impact study as discussed above. The nature of our data on rice farmers, however, allows us to more precisely identify the effects of GM rice. Unlike in the case of BT cotton, we have a fairly large number of observations on individual farm households that produced *both* GM and non-GM rice (on separate plots) during the same year. Hence, when we attempt to estimate the effect of GM rice on yields and pesticide use, we can use a household fixed model that control for all non-time varying household factors.

Regression analysis largely supports the descriptive results (Table 9, columns 3 and 4). Holding all household-level effects, plot-specific inputs and certain other plot characteristics constant, the yields of insect-resistant GM varieties are 6 percent higher than those of non-GM varieties (column 3, row 2). When examining the effects of specific varieties (compared to other conventional varieties—the base category), the yields of GM Xianyou 63 are shown to be 9 percent higher (at the 10 percent level of significance) than other conventional varieties (column 4, row 3). While the yields of GM II-Youming 86 are not found to be significantly different from conventional non-GM varieties, this result in part may be due to the fact that there are relatively few observations (since preproduction trials of GM II-Youming 86 are from one village only and there are relatively few farm households that were partial adopters). Therefore, according to the descriptive and multiple regression analyses, although the evidence on effect of the insect-resistant GM rice varieties on increasing yields is not as overwhelming as that which examines the relationship between the GM rice varieties and pesticides, the GM Xianyou 63 rice varieties does appear to increase yields (between 6 to 9 percent).

The regression analysis illustrates the importance of insect-resistant GM rice varieties in reducing pesticide use (Table 9, column 1 and 2, rows 2 to 6). The significant, negative

coefficient on the GM rice, both variety variable means that GM rice use allows farmers to reduce pesticide use by 16.77 kilograms per hectare (column 1), a reduction of nearly 80% (when compared to pesticide use of farmers using non-GM varieties—Table 7, row 3). The negative and significant coefficients on the GM Xianyou 63 and GM II-Youming 86 variables also demonstrate that each variety significantly reduces pesticides. Although the magnitudes of the coefficients differ, statistical tests show that there is no statistical difference between the actual effects of the two insect-resistant GM varieties on pesticide use (column 2, rows 3 and 4).

3.3 Assessment of Economy-wide Impacts

The economy-wide impact assessment of Chinese biotechnology developments has been conducted with the help of the well-known GTAP modeling framework (Anderson and Yao, 2003; Huang et al., 2004).¹⁵ This modeling framework is a multi-region, multi-sector computable general equilibrium model. The model is built under the assumption that markets function competitively and farm production is constant returns to scale. The model is fully described in Hertel (1997).

While the modeling approach is conventional, it is flexible enough that it enables us to incorporate the factor-specific cost savings that accrue from the adoption of GM crops into our analysis. Specifically, we are able to capture the pesticide- and labor-reducing effects of Bt cotton and GM rice into our analysis. The cost savings are exactly those estimated in sections 3.1 and 3.2. In addition, the multi-sector framework captures backward and forward linkages between the GM crops and the sectors that use the output of the sectors and those sectors that supply them with inputs. In the GTAP model, firms combine intermediate inputs and primary factors land, labor (skilled and unskilled) and capital.

In applying the GTAP model, the authors made substantial efforts in data improvement. The aggregation scheme, macro-economic assumptions, model adjustments, and parameters estimations can be found in Huang et al. (2004). In order to simulate the impacts with alternative scenarios regarding the level of adoption of GM crops by farmers, different adoption rates (ranging from 56 to 95 percent) are assumed.

Commercializing Bt Cotton

The first part of the analysis focuses only on the commercialization of Bt cotton; GM rice is not commercialized in this scenario. The decision of farmers to adopt Bt cotton weighs the cost savings due to its increased yields, labor cost savings and reduced pesticides cost against increased seed costs. Table 10 shows the total impact of adopting Bt cotton and the contributions of these components to the supply price of cotton, relative to the situation without Bt cotton in 2010. The supply price will be 10.9 percent lower in 2010. The yield increasing and labor saving impacts of Bt

¹⁵ This sub-section is a summary of the study by (Huang et al., 2004)

cotton contribute, respectively, 7 percentage points and 3.3 percentage points to this total effect. The pesticide saving impact lowers the price by 1.7 percentage points while the higher seed prices increase the supply price by 1.1 percentage points (Table 10).

There also are wider general equilibrium effects. For example, the lower supply price increases demand. Domestic demand increases with 4.8 percent and exports rise by 58 percent. However, the share of exports in total demand is low, only 0.24 percent. As a consequence, export growth contributes only marginally to the overall growth of cotton demand. The rise in domestic demand is almost completely caused by increased demand from the textile sector. The lower domestic price also implies that cotton imports decrease by 16.6 percent relative to the ‘no-Bt’ case. Higher exports and lower imports imply that the trade balance for cotton will improve by 389 million USD (Table 10).

The textile sector also benefits from the commercialization and spread of Bt cotton. The lower supply price of cotton implies that the supply price of textiles decreases by 0.3 percent. The small fall in textile prices that is associated with falling cotton prices is mainly due to the relatively small cost share of cotton in textiles; cotton accounts for only 2.5 percent of the total cost of textiles. Hence, the 10.9 percent decrease in cotton price leads to a 0.27% ($-10.9\% \times 2.5\%$) decrease in the cost of textiles. As a result, we find that both output and exports increase (by 0.7 percent and 0.9 percent, respectively). At the same time, imports decrease by 0.3 percent. The two sets of price changes cause China’s textile trade balance to improve by 1067 million USD.

Commercializing both Bt Cotton and GM Rice

Impact on the rice sector. The adoption of GM rice generates cost savings due to its yield increasing, labor saving and pesticides saving impact. If the adoption will take place according to the assumed scenario, the supply price of rice will be 12% lower in 2010.¹⁶ The analytical framework allows us to account for the various sources of the price fall. Specifically, almost 8 percentage points can be attributed to the yield increasing impact of GM rice. Labor-savings contributes 4.4 percentage points; pesticide saving 0.9 percentage points (Table 11). In contrast, higher seed prices increase the supply price by 1.1 percentage points. Despite the sharp decrease in price, the impact on output is moderate—only 1.4 percentage points. The low quantity effect is due to a number of factors, but mostly is because rice demand is relatively income and price inelastic. Even though the price of rice falls, consumers do not respond very much. They also do not respond very much to rising incomes. The increase in exports, however, is high in relative terms, rising by 67 percent.

¹⁶ This scenario assumes GM rice commercialization in addition to the adoption of Bt cotton during the period 2002 to 2010. Consequently, the results reflect both the Bt cotton effect and the GM rice effect. Since, the interaction effects between rice and cotton are negligible (comparing the second and third column in Table 11), it is quite easy to see the net effect of the commercialization of GM rice..

While the relative rise in exports is high, the impact on output is limited, since only a small portion (1.2%) of production is exported.

Macro economic impacts. The commercialization of both Bt cotton and GM rice are also shown to have substantial welfare effects. The adoption of Bt cotton and GM rice in China, according to the analysis, enhances welfare (in equivalent variation, EV, terms) by 5.2 billion USD in 2010 (Table 11). Of the rise in EV, 4.2 billion USD comes from GM rice; the rest, 1.1 billion USD is from Bt cotton. The impact of GM rice is therefore 4 times larger than in the case of Bt cotton, which mostly is explained by the fact that the rice sector in China is simply larger than the cotton sector. The results also imply that with the same productivity gains (in our analysis, the gain for both cotton and rice productivity is about 15 percent) more resources are saved in the rice sector.

Trade impact on other regions. Although China witnesses rising exports and/or reduced imports as a consequence of rapid GM adoption, the pattern of global trade in both the textile/garment and the rice sectors is not affected to very great extent. Huang et al. (2004) shows that the impact on major rice importers, such as Africa and rice-deficit developing countries in Asia, is negligible. Major rice exporters in South-East Asia (i.e., Thailand and Vietnam) would experience a drop in net export revenues. However, the total magnitude of the drop should not be expected to be too large since rice exports from China represent only a small share in international rice trade. There also is a negative impact on other major cotton exporters, most notably India and Pakistan. However, beyond these first round impacts, there are few other effects. Although Bt cotton-created cost savings and yield increases translate into lower production costs for China's textile/garment industry, the subsequent shifts will have little effect on other textile-producing countries, such as India or Bangladesh.

Alternative Scenarios: Lower Adoption Rate

Huang et al. (2004) also conducted a systematic sensitivity analysis (SSA) on the productivity parameters of the newly adopted GM technologies. This is important given the uncertainty in the magnitude of impact of the new GM varieties on input usage and yields and ultimately on adoption across China (especially in the case of rice, since it has not been formally commercialized yet). Alternative adoption rates of Bt cotton and GM rice are assumed to be only 56 percent in 2010.

According to the SSA results, the predicted effects of GM crops on productivity and incomes depend importantly on the adoption rate estimates. In fact, the outcomes vary almost linearly with the adoption rates. When adoption rates are lowered by about 40 percent—compared to the optimistic scenario presented above—the value of key outcome variables also fall by about 40% (compare the first two columns called “Total impact”—Table 12). But even at these low rates of adoption, the gains from Bt cotton and GM rice commercialization are still substantial.

4. Agricultural Biotechnology R&D

4.1 Agricultural Biotechnology Programs and Institutions

Agricultural Biotechnology Research Programs

China has developed a number of high profile technology programs since the mid-1980s. For example, the “863” National High-Tech Research and Development Plan initiated in March 1986 by MOST was the first most first, serious program that was developed to support a large number of applied research projects to promote high technology R&D in China. Biotechnology was one of the main key targets of the plan. More recently, the National Basic Sciences Initiative—the ‘973 Plan’ (since it was initiated in March 1997), also was formulated to push ahead China’s research in high-technology. This plan is complementary to ‘863’ and many other national initiatives on high-tech development as it exclusively supports basic research that is supposed to underlie high technology. One of the main emphases of the 973 plan is Life Science research that will ultimately contribute to biotechnology breakthroughs. To strengthen national research and industrialization of agricultural biotechnology, MOST launched a Special Foundation of Transgenic Plants Research and Commercialization (SFTPRC) in 1999. This new program is a unique Foundation promoting both research and commercialization of transgenic plants. Only those projects that are jointly submitted by research institutes and companies are eligible to receive funding from SFTPRC. The Foundation also requires a significant financial commitment from companies to commercialize technology generated by a project. National Natural Science Foundation of China, the major funding agency for basic research, has also allocated significant budget to agricultural biotechnology research since the middle 1980s.

In addition to the high-profile, national efforts, there also are a number of other inter-ministry and provincial funding institutions that have emerged to become important supporters of agricultural biotechnology R&D. For example, MOST and the State Development and Reform Commission (SDRC) jointly sponsored the Key Science and Engineering Program (KSEP) to promote the construction of basic research infrastructure (laboratories and other facilities) since the late 1990s. At local level, almost all provinces have a large-scale program to support high technology; within number of these programs, biotechnology research is targeted. Although some novel research is supported, in many cases the main function of the provincial programs is to support capacity building in the provincial research institutes and to provide match-funding (to match grants from MOST and other national sources). Although there have been a number of important internationally-based collaborative projects, most of these were begun during the 1980s (e.g., grants from the Rockefeller

Foundation and loans from the World Bank), external funding accounted for less than 1 percent of all funding used by China's agricultural biotechnology programs.

Agricultural Biotechnology Institutions

The intense funding efforts by national and provincial authorities have been successful in creating a vast national network of research institutions that are participating in agricultural biotechnology research. By 2001 there were nearly 150 laboratories working on agricultural (both plant and animal) biotechnology; these institutes were located in more than 50 research institutes and universities across China. Over the past two decades, China established 30 National Key Laboratories (NKL). Among these NKLs, 12 are exclusively working on agricultural biotechnology; three others have a major part of their activities on agricultural biotechnology or related programs (Huang et al., 2001). Besides the NKLs, there are a large and expanding number of Key Biotechnology Laboratories and agricultural biotechnology research programs within China's ministries and at the provincial level.

During the past decade a large, network of research programs have grown up and they are managed by a diverse set of national and provincial agencies. At the national level, MOST, the Chinese Academy of Sciences (CAS), the Ministry of Agriculture (MOA), the State Forestry Agency (SFA), and the Ministry of Education (MOE) are the major authorities responsible for managing agricultural biotechnology research. The programs within each of these agencies can also be vast and complicated. For example, under the MOA, there are three research academies—the Chinese Academy of Agricultural Sciences (CAAS); the Chinese Academy of Tropical Agriculture (CATA); and the Chinese Academy of Fisheries (CAF). Among the 37 institutes in CAAS in 2001, there are 12 institutes, 2 National Key Laboratories and 5 Key Ministerial Laboratories that are involved in biotechnology research programs. To consolidate and coordinate their academy-wide research on biotechnology, in 2001 CAAS established a National Key Facility for Crop Gene Resources and Genetic Improvement, which has evolved into one of the most modern biotechnology research centers in the developing countries. The CAF and the CATA also have several large biotechnology laboratories, and each has hosts a NKL for biotechnology. The other centers of agricultural biotechnology are equally as complicated.¹⁷

While the programs at the national level make up China's best known and productive centers of agricultural biotechnology research, research at the sub-national level also contributes to the development of China's agricultural biotechnology. Typically

¹⁷ Under the CAS there are at least 7 research institutes and 4 NKLs that focus on agricultural biotechnology. Research institutes within the Chinese Academy of Forestry (CAFo) under the State Forest Bureau and numerous universities (i.e., Beijing University, Fudan University, Nanjing University, Central China Agricultural University, and China Agricultural University) under the Ministry of Education (MOE) are examples of other institutions conducting agricultural biotechnology research. There are 7 NKLs located in 7 leading universities conducting agricultural biotechnology or agriculturally related basic biotechnology research. Other public biotechnology research efforts on agriculturally related topics include agro-chemical (e.g. fertilizer) research by institutes in the State Petro-Chemical Industrial Bureau.

agricultural biotechnology programs follow a similar institutional framework to that at the national level. Each province has its own provincial academy of agricultural sciences, and at least one agricultural university. Each academy or university at the provincial level normally has one or more institutes or laboratories that are focused on agricultural biotechnology. Even at prefecture level, there are a number of research institutes that have been working on applied GM research. Finally, it is worth noting that the number of both national and provincial biotechnology programs and institutes continue to increase.

4.2 Agricultural Biotechnology Research Capacity and Investment

The creation of a modern and internationally competitive biotechnology research and development system requires substantial investment in human resources and basic infrastructure. Since the early 1980s, China's public investment in biotechnology has increased significantly and this has created a large and growing number of scientists that are working on agricultural biotechnology. The data presented in this sub-section are based on a recent nationwide survey on agricultural biotechnology research institutes by the Center for Chinese Agricultural Policy.

Agricultural Biotechnology Researchers

According to our survey, since the mid-1980s the number of agricultural biotechnology researchers has increased steadily (Table 13). In 2003, about 5770 researchers were working on agricultural biotechnology, of which, about 3200 were considered part of their laboratory's professional staff. Plant biotechnology accounts for nearly 60 percent of the total research staff; those working on animal and microorganism biotechnology research account for 30 and 10 percent, respectively.

Surveys of the same research institutes conducted during earlier years (also led by CCAP) demonstrate that the quality of human resources which are focused on biotechnology research has improved over time ((Huang et al. 2001). Among the professional staff, the share of researchers with Ph.D. degrees increased from only 2 percent in 1986 to more than 20 percent in 2000. While the share of researchers with Ph.D. degrees in biotechnology is still low by international standards, it is interesting to note that this share is much higher than those in the general agricultural research system. In China's national agricultural research system, Ph.D. researchers accounted for only 1.1% of the total professional staff in 1999 (Huang, Hu, and Rozelle, 2001).

Agricultural Biotechnology Investment

Even more spectacular growth has occurred in China's biotechnology research investment (Table 14). China's biotechnology research investment was trivial in the early 1980s (MOST, 1990). While there are no statistics available from official sources, the estimates based on our national survey show that biotechnology

investment has grown substantially. For example, the estimated investment in agricultural biotechnology research was only 10 million US\$ in 1986 when China formally started its 863 Plan. By 1990 China's investment grew to 25 million USD. During this period, the research project budget nearly tripled and expenditures on laboratory building and equipment nearly doubled. While the growth rate of biotechnology research investment slowed between 1990 and 1995 (this is expected as the large investment in biotechnology equipment was nearly complete in the early 1990s), the annual growth rate in the research project budget in real terms remained as high as 6 percent during this slow growing period.

After slowing in the early 1990s, however, the growth of China's biotechnology research investment accelerated during the past decade. Investment increased from 33 million USD in 1995 to 104 million USD in 2000, representing an annual growth rate of about 26 percent. In 2000 to 2003, the budget was further doubled (Table 14). In 2003, China spent nearly 200 million USD (or 953 million donors in PPP terms) on agricultural biotechnology, of which 120 million USD spent on plant biotechnology.

While sometimes the media and international reports highlight the role of foreign Life Science firms and the domestic private sector, investment in China's biotechnology is overwhelmingly from government sources. According to our survey of the 46 biotech research institutes, public investment accounted for 97 percent of the total agricultural biotechnology budget in 2003. Budgets from publicly-funded competitive grants for research accounted for two thirds of the total budget and this share also has shown an increase over time, reflecting China's biotechnology development moving from a capacity building stage to a research stage.

Investment in agricultural biotechnology is expected to grow in the future. Our recent interviews with officials and research administrators from the Ministry of Science and Technology confirm that the Ministry is continuing to accelerate its investment in national biotechnology program. Many leaders and research administrators publicize their plans for making China one of the premiere centers of the world's plant biotechnology research. Such ambitions are embodied in China's 11th Five-year Plan for biotechnology development (2006-2010).

4.3 Remaining Challenges

While the institutional framework for supporting agricultural biotechnology research program is impressive, there are still challenges. Most immediately, the coordination among institutions and consolidation of agricultural biotechnology programs will be essential for China to create a stronger and more effective biotechnology research program in the future. Despite research capacity in terms of both quantity and quality has also improved significantly, human capacity may need further improvement if China intends to establish an internationally competitive biotechnology research

program and to achieve the overall goal of promoting agricultural biotechnology in China.

China also needs to set clear priorities, ones that will bring the maximum benefit from their investments and help the nation meet its strategic goals. Examination of the past research foci of agricultural biotechnology research reveals that China's investments appear to be emphasizing technologies that will allow them to meet their food security objectives as well as several of the demands that farmers have for specific traits—such as, technologies that reduce pesticides and raise productivity and competitiveness. Research administrators also are investing heavily in agricultural biotechnology investments that will aid the development of stress tolerance, which might not only have implications for food security, but also for poverty alleviation. This effort may need further emphasized in the future.

There are also other important strategic questions that require consideration. Should China continue to invest only its own resources in biotechnology or should it encourage investment by the foreign life science firms? What should be the role of domestic private sector in China's future agricultural biotechnology development? Does China need to continue expanding its biotechnology at sub-national level or should it consolidate its resources? How can biotechnology programs at different levels (and by different prospective actors) be coordinated to maximize the efficiency of the nation's research investments?

5. Agricultural GMO Biosafety Regulation

5.1 Institutional Setting

After nearly a decade of experience in creating a framework for regulating biosafety, China has developed a comprehensive biosafety regulatory system on GMOs. Guiding the overall process, the Joint Ministerial Meeting (JMM) has become the highest placed institution that is in charge of directing and creating China's comprehensive policy on GM regulation. The JMM was established by the State Council, China's highest governmental body through the issuance of "Regulation on the Safety Administration of Agricultural Transgenic Organisms." The JMM is composed of the highest representatives from the MOA, the National Development and Reform Commission (NDRC), the Ministry of Science and Technology (MOST), the Ministry of Health (MOH), the Ministry of Commerce (MOC), the National Inspection and Quarantine Agency, and the National Environmental Protection Authority (NEPA). The group of officials is primarily responsible for the coordination of several key issues related to agricultural GMO biosafety, including the responsibility to examine and approve and set up all policies and major regulations that relate to agricultural GMO commercialization, labeling, imports and exports.

The JMM's structure provides a key role in agricultural GMO biosafety management to the Ministry of Agriculture (MOA). Following the directives of JMM, China's MOA is the primary institution in charge of the implementation of agricultural biosafety regulations and GMO commercialization. Within MOA, leaders have set up the Leading Group on Agricultural GMO Biosafety Management to manage GMO biosafety. The routine work and day to day operations, which are directed by the Leading Group, are carried out by the MOA-based Agricultural GMO Biosafety Management Office (BMO).

Although initially one of most important tasks of GMO biosafety management, scientific assessments of new technologies, also was under the direct management of MOA, since 2002 China's top leaders have made National Agricultural GMO Biosafety Committee (BC) a national level commission (although it is still hosted by MOA). Currently, the BC is composed of 56 expert/scientific members.¹⁸ They meet twice each year to evaluate all biosafety assessment applications related to experimental research, including: a.) field trials (small-scale, controlled trials); b.) environmental release trials (medium-scale, more-open field trials, typically held in experiment station fields); c.) pre-production trials (large-scale field trials that sometimes can be held in farmer fields); and d.) the commercialization of agricultural GMOs. The main task of the BC is to provide technically-based, recommendations of approval for the applications of scientists and research administrators that want move their experimental technologies into progressively more advanced stages of trials and ultimately to commercialization. Based on the BC's technical assessments and other considerations (e.g., a wide array of less, quantifiable social, economic and political factors), the BMO prepares an overall set of recommendations for approval that is sent to the Leading Group for the final decision.

With a few exceptions, the BMO and the Leading Group with the assessments of the BC generally make the final decisions on GMO-related applications. For the commercialization of new and important GM crops, the Leading Group has chosen (or been required) to consult with the JMM and top national leaders in making its final decisions. For example, the decision to commercialize GM rice will undoubtedly be made by the State Council in consultation with the JMM and Leading Group. The approval of new varieties of Bt-cotton and decisions to move new rice varieties to pre-production trial can be made by the Leading Group on its own. In part because of the sharing of responsibilities on these major decision, in the case of high-profile technologies or experiments about which MOA/Leading Group members do not have a clear view, there is a good deal of uncertainty in the decision making process which

¹⁸ The membership is characteristically created around areas of expertise. For example, 29 of the members are responsible for making decisions and making recommendation on GM plants; 9 members are dedicated to examining recombined microorganisms for plants; 12 for transgenic animals and recombined microorganisms for animals; and 6 for GM aquatic organisms. These members all only work part-time for BC and are mainly composed of scientists from different disciplines, including agronomy, biotechnology, plant protection, animal science, microbiology, environmental protection and toxicology. A few members also have positions within the MOA and other agricultural-oriented government agencies.

can lead to substantial delays in acting on matters that require final approval. The most prominent example of this is the case of the commercialization of GM rice.

Other ministries have other duties involved with biosafety regulation of GMOs. For example, the MOH is responsible for the food safety management of biotechnology products. The MOH has managed the technical-based issues of GMO-related food safety by setting up an Appraisal Committee. The Appraisal Committee is made up of experts and scientists in the areas of food health, nutrition and toxicology. Acting on decisions of the Appraisal Committee, the MOH has two main functions in the biosafety regulation chain: it issues formal assessments of the food-safety properties of GMOs; and it grants food safety certificate for any novel GMOs. In particular, the food safety certificate is an integral part of the application materials that scientists/research administrators need to submit to the BMO and BC during the process of assessing the overall biosafety of each GMO experiment and commercialization application.

The State Environmental Protection Authority (SEPA) also participates in GMO biosafety management through JMM. Most importantly, SEPA has taken on the responsibility of managing and implementing international biosafety protocols. Its primary domestic duties in the biosafety are mainly focused on understanding and reporting on how the release of GM crops would affect biodiversity.

As a large and ecologic diversified country, China also has been trying to set up a local network of GMO biosafety regulation and management offices. By 2005, 26 provinces that have agricultural biotechnology R&D programs will have established provincial-level agricultural GMO biosafety management offices. Each of these offices is housed in the provincial agricultural bureau. The primary roles of these local biosafety management offices are to monitor and inspect the performance of research, field trials and the result of decisions to allow the commercialization of agricultural biotechnology products in their provinces. In theory, local offices also are able to conduct initial assessments of local GMO's field trial applications and submit these applications to the National Biosafety Committee for assessment. Practically, however, provincial biosafety offices play at most only a limited (and, in some cases no) role in the biosafety assessment of field trials. Hence, their primary role is to monitor the local implementation of biosafety regulations.

5.2 Biosafety Regulations

In response to the emergence of commercially viable agricultural biotechnology products in China, MOST issued the first biosafety regulation statement, "Measures for Safe Administration of Genetic Engineering," in 1993. This first regulatory statement can best be categorized as China first comprehensive set of biosafety guidelines. The body of the regulatory document consisted of a set of general principles, the delineation of a series of categories of technology that were considered

to be inherently “safe,” the process of risk evaluation and a preliminary procedure guiding the application and approval process, rudimentary research and commercialization safety control measures, and a set of legal responsibilities (Table 15). After the general guideline was decreed, MOST required relevant ministries to draft and issue their own, more detailed set of biosafety regulations.

Following MOST’s guidelines, in 1996 MOA issued its first set of biosafety regulations, called the “Implementation Measures for Safety Control of Agricultural Organism Biological Engineering.” The initial set of regulations covered plants, animals and microorganisms (Table 15). One subset of the guidelines focused on spelling out the detailed procedures that research institutes and other agencies and firms would need to follow to meet the minimum level of biosafety standards at each stage of GMO development. In the mid-1990s, separate biosafety standards were set up for small-scale field trial, environmental release trials and commercialization. Acting on the authority of the initial guidelines, MOA officials also set up the first Biosafety Committee in 1997 as a body that would provide the Ministry with expert advice on biosafety assessment.

With continued development of agricultural biotechnology, rising GMO imports and the emergence of concerns about consumer health and perceptions of food safety, since the late 1990s, China has periodically amended its biosafety regulations. In particular, in May 2001 the State Council decreed a new set of biosafety regulations covering plants, animals and microorganisms to replace the previous one issued by MOA in 1996 (Table 15). The State Council’s new regulations contained several important changes. In part as a way to gather more information, the new regulations allowed for the establishment of a new stage of assessment for GMO products. In addition to small-scale field trials and medium-scale environmental release trials, scientists were required to have their technology enter and successfully pass a pre-production trial stage. In other words, prior to being able to commercialize a GM product, the developing scientists had to pass three stages of approval instead of two.

In addition to changes to the R&D procedures, the State Council’s new regulations contained a number of other important amendments. A new set of regulations were promulgated on processed food products, which initially were not covered. Labeling became required on all products that contained GM food components.¹⁹ In response to rising imports of soybeans and the prospects of maize imports, there also were a series of new regulations on the export and import of GMOs and any food product that contained GMOs. The national guidelines also pressured provincial-level and subprovincial agencies to implement stricter GMO monitoring guidelines.

As the same time as the State Council’s new regulations were being worked out, in April 2002 the Ministry of Health (MOH) also promulgated its first comprehensive set

¹⁹ The first list of agricultural GMOs that were required to be labeled included 17 products from 5 crops. They are soybean seeds, soybeans, soy flour, soy oil, soy meal; corn seeds, corn, corn oil, corn flour; rape seeds for planting, rape seed, rape seed oil, rape seed meal; cotton seeds for planting; tomato seeds, fresh tomatoes, and tomato sauce.

of regulations on GMO food hygiene. Among other conditions, this set of regulations required that all fresh and processed food with any GMO component must be approved by MOH before being sold in any market. Their regulations also duplicated the State Council's call that GMO foods were to be labeled.

Although there have been fewer food safety concerns, in order to enhance the management of Bt cotton varieties, MOA released another set of complementary regulations in 2004. The actions by MOA were largely being made in response to the problems of the proliferation of unapproved (and illegal) Bt cotton varieties in widespread areas of China's cotton producing areas in northern China and in the Yangtse River Basin. The strategy of the new regulations was two-fold. On the one hand, biosafety regulation procedures were made more comprehensive. For example, MOA began to require that all newly developed GM variety must already have a safety certificate from MOA before varieties are allowed to enter regional variety trials (the last stage in the process by which crop varieties are certified for commercialization). In order to become certified, the applicants seeking approval for their new cotton varieties, in addition to the yields and other performance information, also must present a certificate that a variety is GM or non-GM. The tests are conducted in a series of MOA-designated testing institutes/organizations.

On the other hand, the MOA also has sought to simplify the process of certification and approval. Above all, MOA has stated that any Bt cotton variety which has received a production safety certification (or commercialization certification) from one province can directly apply for a safety certificate from another provinces (as long as the provinces are within same cotton-ecological region—of which there are three in China).²⁰ In addition, the developers of any variety can directly apply for safety certificates in one province if the new variety was developed from a parent variety that already had been granted a safety certificate in the past.

The impact of the stream-lined regulation procedure has been significant. In 2004, the number of varieties that applied for and received biosafety certificates soared. In total there were about 130 new certificates issued, far above 2003. Interestingly, nearly all of these newly approved varieties were varieties that had already been planted in farmer fields.

Although there has been a lot of improvement in China's biosafety regulations, there is still room for improvement. For example, when compared to the standards of other developing country, China's regulations can be considered to be fairly comprehensive. However, when compared to those in many developed countries, China's regulations are not only considered incomplete, they also have, until now, been implemented in a fairly loose fashion. As such, many observers believe that the regulations have been fairly limited in their effectiveness during the first several years.

²⁰ In addition, the new regulations state that any Bt cotton variety (including variety line) received a production safety certification (or commercialization) from any region can directly apply for a safety certificates in *one* provinces in another cotton-ecological region.

Recognizing the comprehensiveness of regulations outside of China, national leaders, at least so far, have taken a fairly accepting view of results from biosafety procedures that affect imported GM commodities. If the gene under question has passed through the biosafety regulatory process in the United States or Canada, it has generally been assumed to meet China's food safety and environmental regulations. The only additional requirements are imposed when a foreign technology is imported into China. In this case, the new technology must be tested for its efficacy in controlling pests and/or disease under actual field conditions in China.

5.3 Biosafety Regulation Investments

When China started its commercialization of Bt cotton in 1997, the budget allocated to both biosafety research and regulatory management was trivial. In 1997, we estimated the total budget allocated to both biosafety research and administration of biosafety management was only 120 thousand USD (Table 16). Nearly half of this budget was used in biosafety research (e.g., food safety and environmental safety) on Bt cotton lines that were generated by CAAS. The rest were used in regulatory costs of running the Biosafety Committee.

Table 16 shows that there have been substantial increases in government budgetary allocations for research on and the management of agricultural biosafety. The rapid growth of agricultural biotechnology and the commercialization of Bt-cotton in the late 1990s posed a challenge to the capacity of China's biosafety regulation. In response to this challenge, China raised the annual budget for agricultural GMO biosafety research from 0.6 million RBM in 1999 to nearly 7 million RMB in 2002. By 2003, the annual investment in agricultural GMO biosafety research reached 14 million RMB. In contrast, considerable public investment effort has also been directed towards building the capacity for regulation of GMO biosafety at both the national and provincial levels. Currently, China spent about 3 million USD annually on agricultural biosafety related works (excluding the expenditure required to implement its labeling and market inspection duties).

5.4 Remaining Challenges

Despite the great efforts and investments that have been made to create the initial set of institutions and regulatory bodies for managing biosafety, the record of the bio-safety committee in regulating GM events in the field has not been very effective. China's agriculture is composed of millions of small farmers, thousands of seed companies, and hundreds of crop breeding research institutes. After the first five varieties of Bt-cotton were approved for commercialization in five provinces 1997, many research institutes in almost all provinces have generated a whole host of their own Bt-cotton varieties in their breeding programs.²¹ In many of the cases, existing (approved)

²¹ One variety NC33B Bt-cotton from Monsanto was commercialized in Hebei, the other four varieties from CAAS

varieties are being used in the new varieties by backcrossing methods. As the demand for Bt-cotton seed increased, seed stocks for most of the new varieties were generated and disseminated through conventional seed trial and regulatory system. Most of the varieties completely bypassed the BC and other formal institutional structures that were set up to regulate GM varieties. In fact, our field surveys reveal that the number of illegal Bt-cotton varieties far surpassed the number of legal Bt-cotton ones after only several years of commercialization.

Although the biosafety regulation and implementation system have been established and improved over time in China, several additional problems have emerged during their implementations. First, the system charged with monitoring GMO production at local level is relatively weak. For example, between 1999 and 2001 we surveyed 854 Bt cotton farmers who had adopted 28 Bt cotton varieties. The 28 varieties that we identified actually had 73 different varietal names. Of them, only 13 Bt cotton varieties (or 46% of them) had been approved for commercialization by the BC and were registered with the BMO. Such a record, of course, implies that there are a large number of illegal Bt cotton varieties that have been disseminated through China's conventional (or non-GM) seed system. Hu et al. (2005) shows that while both legal and illegal Bt cotton varieties do have some tendency to reduce pesticide use, the yield performance of approved and non-approved varieties differ widely. Specifically, the yields of legal Bt-cotton varieties are higher than illegal Bt-cotton. In fact, unapproved Bt cotton varieties only yield the same as non-Bt cotton varieties. Hence, on average, farmers have benefited much more from legal Bt-cotton varieties that have gone through the regulatory system.

Second, there is a recognition by sector leaders that China need to have a better system for monitoring the performance of GM crop trial before commercialization, particularly during the pre-production stage. For example, the recent experience in Hubei province, in which farmers in preproduction trials sold their output onto the market, shows the absence of effective monitoring. Officials recognize such incidences, in fact, hurt the entire GM R&D and commercialization effort as they undermine the confidence in the system's ability to effectively regulate GM biosafety more generally.

Third, officials also now recognize that there is further need to improve the transparency of biosafety evaluation process. Although much improved since 2002, scientists are summarily subject to a series of processes that are unclear and often at least perceived to be arbitrary. The main problem appears to be that the decision making criteria on which decisions are based are not always explained directly to the scientists or research administrators that are trying to get their new technologies approved.

were commercialized in Shanxi, Anhui, Shandong and Hubei (one variety in each province).

Fourth, there are many remaining issues about who should be bearing the cost of biosafety regulation. Above all, it is unclear who should be responsible for financial supporting the biosafety assessments throughout the GMO trial process. If the technologies are generated by the public sector, who should fund the effort that is need to push the new technology through the biosafety regulation procedures after the laboratory research is completed. Especially since the cost of meeting biosafety assessments have risen sharply, many provincial and prefectural research institutes have found that they have been unable to finance them even after they generated what they consider to be high quality lines of GMOs. In the presence of weak monitoring at local level, the lack of funding to conduct biosafety field trials (as well as the time and expertise that is required by those that go through the application procedure), it is not surprising that there has been such a proliferation of illegal Bt cotton in recent years—especially prior to the reforms of 2004.

Finally, although the investment in agricultural GMO biosafety regulatory has increased significantly, an effective biosafety regulatory system needs further increases in their budget. In 2003, the total public budget allocated to agricultural GMO biosafety regulatory was equivalent to only 1.4 percent of the government's expenditure on agricultural biotechnology (Table 16, the last column). Clearly, this amount is insufficient to create and sustain an effective biosafety program.

6. Commercial Dissemination: Policy shifts and Impacts

6.1 Intellectual Property Rights

While no one claims that intellectual property rights in China are strong, the experience of the last two decades demonstrates that they have improved remarkably over time. Prior to the late 1990s neither plant breeders nor seed companies had any legal control over the plant varieties or genes that they created. It was legal for a seed company to take a new variety that another company had developed and reproduce and market that variety. Also, there was no restriction on the use of the new variety as a parent in the development of another variety. The varieties could be sold and marketed legally without paying any licensing fees or royalties to the original creators. The use of varieties of other breeders as parents was a common practice in the 1980s and still is today.

In 1997, however, things began to change. Above all, China passed its first Plant Variety Protection (PVP) Act. Legislators developed a fairly comprehensive legal framework based on UPOV.²² China first started accepting applications for PVPs in 1999 and currently all major crops are eligible for plant variety protection except cotton.

²² The French acronym for the organization that manages the international treaty that protects plant breeders rights.

While it is still unclear what the impact of PVP has been on the revenues of breeding institutes or seed companies or the incentives of the scientists and administrators that work in them, recent research has shown that there is increasing interest in applying for patents by individuals, firms and institutes in China. Using a data base of all major varieties in China for 22 crops, Hu et al (2005) show that annual applications for plant variety certificates (PVCs) increased from 115 in 1999 to more than 400 in 2003. Although research institutes have accounted for most of the applications (59 percent), companies and individuals applied for 33 percent of the PVCs .

There are still gaps in China's IPR regulation. Most glaringly, the PVP still does not cover cotton, and even if it did, it would not restrict the use of varieties as parents in the production of other varieties. PVP has a research exemption that explicitly allows companies or research institutes to use commercial varieties as parents to develop new varieties. In addition, it gives no protection to novel genes that have been developed by scientists.

In response, there have been a variety of ways that actors in the seed and biotechnology sectors have responded. For example, the way in which China's firms try to prevent their proprietary varieties and novel genes from being used by other scientists without permission (and perhaps begin to receive some licensing payment) is through the patent system. Dr. Guo Sandui of CAAS received a patent on the Bt gene that he developed, the one that is being used in all of the CAAS varieties (Fang et al 2001). Monsanto has patents on several genes that are important in the production of transgenic plant varieties. These patents cover genes that are inserted into plants to make plants resistant to certain classes of insects; they cover processes that create transgenic cotton varieties; and they cover genes that promote the expression of the gene to which they are attached.

In addition, firms also can try to use trademarks—another form of intellectual property—to protect their technology. Biocentury, a company that manages CAAS' Bt cotton, has trademark protection on their name and some components of their technology (Fang et al 2001). Monsanto's Bollgard trademark on its Bt cotton varieties prohibits other firms from using the name on their varieties.

While seed companies in the cotton industry have taken steps to protect their seed varieties, it is unclear how effective their actions have been. Interviews with CAAS officials, Biocentury Seeds and international biotech companies in China revealed that current laws and enforcement of IPRs provide little protection. We were told that the innovative cotton seed firms have had little success in keeping other firms from copying their varieties or trademarks. New entrants in the Bt seed market reproduce, backcross and market the varieties developed by both domestic and foreign life science firms/research institutes. In fact, we estimate that while the varieties with CAAS's gene covered 2.25 million hectares in 2004 (or 61 percent of the national Bt cotton area, Table 2), the Bt cotton varieties sold by CAAS and BioCentury Co. covered only 5

percent of total Bt cotton area in the same year. The manager of BioCentury said that the rate was even lower (only 3 percent) in 2003 when Bt cotton varieties with CAAS gene covered 1.51 million hectares (or 50 percent of total Bt cotton area, Table 2). Only a slightly higher rate was recorded for cotton varieties with Monsanto's Bt gene. According to the Delta and Pine Land representative in Beijing (May 13, 2005) legitimate Bollgard seed covered less than 5 percent of the Bt cotton market in 2004. despite that fact that varieties with Monsanto's gene cover at least 39 percent of the total Bt cotton areas. Clearly, IPR is a problem facing those that try to operate and innovate in China's agricultural sector.

6.2 The Seed Industry

The seed industry, like so many sectors in China's economy, also has evolved over time. In the mid 1990s local and regional State Owned Enterprise (SOE) seed monopolies dominated China's seed industry. In total, 2700 SOEs operated in their local counties, prefectures and provinces. In most counties, only the local region's SOE was allowed to sell seeds of the major crops. Regulations banned the participation of non-SOE seed firms in the production, distribution and sale of hybrid maize and rice. In the typical case, the county- and prefecture-based SOEs sold their seed through township agricultural extension agents. Indeed, during the 1990s agricultural extension agents earned a large share of their income from selling agricultural inputs, including seed (Nyberg and Rozelle, 1999). The practice continues today.

Since the mid 1990s the laws and policies that govern the seed industry have changed in such a way that a commercial and competitive seed industry has begun to evolve. New firms have entered the market. New sources of investment in the industry have emerged. Although still low, foreign investment has begun to enter into the seed industry. Perhaps more than any other part of the seed industry, these changes have been particularly important in the cotton seed industry.

In the late 1990s reformers began to press for a more modern, less government-dominated system. In 2000 the government passed a new seed law that for the first time legally defined a role for the private sector. Among other parts of the legislation, the law makes it clear that any entrepreneur who has access to the required minimum amount capital and facilities can sell seed. Private companies are allowed to sell seed, including all varieties of hybrid maize and any variety of GM or non-GM cotton that were bred by the public institutes. With the passage of this legislation, the protection of the monopoly positions of county, prefectural and provincial seed companies was formally removed. New distribution channels for seeds opened along side the agricultural extension system which traditionally sold SOE seed to farmers. All firms—private, quasi-commercialized SOEs and traditional SOEs—were allowed to apply for permits to sell seed in any jurisdiction. Measures also were put into place that allowed firms to have their seeds certified at the provincial level which would

entitle them to sell seed in any county in the province. By late 2001 nine companies had permits to sell seed anywhere in the country. For the first time, it became feasible for national companies to establish their own distribution and retail networks. At the other end of the spectrum thousands of small seed companies opened up to supply local needs.

In the cotton seed industry, especially in the part of the industry that is involved in the creation and marketing of genetically modified cotton, the government's recent policy efforts have been effective in encouraging the development of a competitive, commercial seed industry. Specifically, there have been three fundamental shifts in the structure of the seed industry: the appearance of large commercial seed companies that operate at the regional or national level; the rise of small, private foreign firms (although they still play a somewhat limited role); and the emergence of small, private seed firms. Despite these shifts the traditional seed producers (the local, county- and prefecture-owned SOE seed enterprise) and their distribution channels (the agricultural extension system, and in the case of cotton, the cotton office) are still active.

6.3 Policy Shifts and the Impact on Producer Efficiency

Based on the same data presented in section 3, we seek to answer three questions: a.) Will stronger IPRs on novel genes and varieties provide greater incentive to do research and promote efficiency in cotton production? b.) Will reforms to the seed industry help or hurt production efficiency? c.) Will more effective approval procedures and bio-safety regulation enforcement benefit China's farmers (a question related to the issue raised in section 5)? More comprehensive discussion of these issues can be found in Hu et al. (2005).

In carrying out our study, we need to know the sources of seeds. While the respondents were able to state precisely from which source their seed came, it was more difficult for them to identify the company which produced their varieties. For example, farmers that bought from the seed companies typically could distinguish between "foreign seed" varieties that were using the Monsanto gene and those that were developed with the CAAS gene ("not foreign seed"). However, the same farmers often were not sure whether the seed company from which they bought their seed was actually selling legitimate seed or not (that is if they were actually produced and distributed by either Jidai or Biocentury or their authorized partners and/or dealers). From our field work, we revealed that the legitimacy of seed could be determined mostly by looking at the price that farmers paid for their seed and whether or not the seed was delinted and/or treated. Legitimate Jidai and Biocentury seed was always delinted and treated; legitimate seed also was nearly always sold for a fixed price, about 40 yuan per kilogram. As a consequence, when farmers reported that they bought seed for less than 30 yuan per kilogram, even when they called the seed 33B (a common name for the seed sold by Jidai), we assume that they were buying illegitimate seed. Likewise, when the farmer said that he/she purchased loose and

fuzzy seed (which showed that it was not delinted seed/and not pink which showed that it had been treated with fungicide) even if he/she said the seed was from Jidai or Biocentury, we also assume that the seed was illegitimate (since all legitimate seed was delinted and treated).

Using the data from our survey under the assumptions about the source of the seed discussed above, we divided all cotton seed used by farmers into 9 types: legitimate MDP (high priced, delinted and treated);²³ illegitimate MDP (low-price or fuzzy and non-treated); legitimate CAAS (high priced, delinted and treated); illegitimate CAAS (low-price or fuzzy and non-treated); seed from a seed company that was unapproved (neither MDP nor CAAS varieties); seed that came from the Agricultural Extension Station/Cotton Office; seed production base (also including a few observations bought from Ginning Factory , both are owned by county's Agricultural Bureau); or self-saved. With such categorizations, our first exercise was to assess whether proprietary Bt varieties have any economic advantage over non-proprietary varieties (legitimate MDP vs. illegitimate MDP; legitimate CAAS vs. illegitimate CAAS). Second, we sought to analyze the impact of a strong bio-safety management system (Approved varieties—e.g., legitimate MDP or legitimate CAAS vs. Unapproved varieties). Third, we tested whether or not the seed sold through the market (whether legitimate or not, including the seed sold by the seed production base and Ginning Plant) performed as well as seed that was sold through traditional non-market channels (Agricultural Extension Station or the Cotton Office). Along these lines we also tested whether or not the varieties of the multinationals performed as well as domestic ones (legitimate MDP vs. legitimate CAAS).

Identifying the Differences in Efficiency

To understand the net effect of the seeds (and genes) from different sources, we adopted a multivariate production function approach using the pooled data (for three years) from five provinces. We followed the similar approach that used in our impact studies presented in section 3, but with the inclusion in the specification of an additional set of seed dummy variables in both the pesticide and yield equations. The results of regression are presented in Table 17. Hu et al. (2005) fully explore the impacts of various factors on pesticide use and crop yield, but in this paper, we pay attention only to 3 issues raised above.

The results of models which are empirically estimated are presented in Table 17. They show that there is the potential positive effect of IPRs can be analyzed by looking at the differences between *Legitimate* and *Illegitimate MDP* and *CAAS* varieties. If IPRs were enforced, the illegitimate seed would not be available and more farmers would be using the legitimate seed. The point estimates suggest that this could increase the yields of farmers and reduce their pesticide costs. When farmers used either type of legitimate seed (Legitimate MDP or CAAS), pesticide use fell between

²³ Monsanto-Delta and Pineland (MDP) joint venture (“foreign seed”).

39.77 and 41.45 kilograms per hectare (rows 12 and 14, Table 17). Statistical tests (not shown) demonstrate that there is no statistical difference between the legitimate MDP and CAAS varieties. When using the illegitimate seed (Illegitimate MDP or CAAS), the fall in pesticide use is less (and statistically so — 30.57 and 33.52 kilograms) than when they used legitimate varieties (rows 13 and 15). If IPR regulations had kept out unauthorized varieties that were being sold as MDP or CAAS varieties, the use of pesticide by farmers would have been less.

The effect of enforcing IPRs is even clearer in the yield equations. The yields of the legitimate MDP variety were 25.7 percent above those of the baseline conventional varieties; the yields of illegitimate MDP varieties were only 12.8 percent more. The difference was statistically significant. The same was true in the case of the CAAS varieties of Bt cotton. The yields of the legitimate variety were 19.2 percent more than those of conventional varieties while illegitimate versions of the CAAS varieties were not statistically different than conventional varieties. The benefits of the legitimate varieties on the yields of Bt cotton are clear.

The results also allow us to see the possible effect of enforcing bio-safety regulations—especially in the case of yields. We can see the benefits of bio-safety regulation by comparing the coefficients of the seeds with an approved Bt gene (those associated with the variables representing MDP and CAAS varieties) and the *Unapproved* Bt genes. The pesticide equation shows little difference in the reduction of pesticide use. The seed that did not go through the bio-safety regulation process is almost as effective (38.53 kg reduction) as the legitimate MDP and CAAS varieties (39.77/41.45 kg and statistically indistinguishable—column 1, rows 11, 13 and 15). However, the yields of unapproved varieties are lower. The yields of unapproved varieties are not statistically different from conventional varieties of cotton, while the approved MDP and CAAS varieties yield 19.2 to 25.7 percent higher (column 2, rows 11, 13 and 15).

Finally, our results suggest that the reform of seed markets also have improved the performance of Bt cotton varieties. The pesticide reduction of varieties of seed sold through traditional channels (*Cotton Office* and *Ag Extension Station*—rows 16 and 17) is mostly less and the yields are almost all lower than those purchased through the market (the other 5 seed sources—rows 11 to 15). Hence, when taken together, the econometric analysis provides strong and consistent support that suggests that if China had improved enforcement of IPR, if leaders had implemented more effective bio-safety regulation and if reforms had made seed markets more competitive, pesticide use would have been significantly lower and yields higher. Clearly, all of these results show the importance of promoting a stronger system of IPR, a more effective network of biosafety regulatory bodies and a stronger seed industry.

7. Concluding Remarks

China considers agricultural biotechnology as one of its most important, strategic tools for improving national food security, raising agricultural productivity and creating a competitive position for its farmers in international agricultural markets. Despite the growing debate worldwide on GM crops, our review of the literature shows that China has developed and is beginning to disseminate a wide array of agricultural biotechnology products since the mid-1980s. Research and development has consistently increased and accelerated in recent years. China now has several important genetically modified plants that are in the pipeline for commercialization that have the potential for creating high returns for domestic farmers.

The results of impact studies in farmer fields are strong and consistent across crops. For example, research show that China's GMO technology has benefited millions of farmers. At the farm level, the rapid adoption of Bt cotton by farmers has led to higher yields, reduced pesticide costs, reduced labor allocations (for spraying), as well as reduced the number of times that farmers have reported being sick from the process of the application of dangerous pesticides. The results based on our own GM rice pre-production surveys demonstrates that the effect of GM rice on pesticide use, crop yields and farmer health (related to pesticide uses) are similar and singularly beneficial to farmers. At the sectoral and macro level, our study shows that the economic gains from GMO adoption are substantial. In one scenario, in which China's leaders allow for the commercializes both Bt cotton and GM rice, the welfare gains amount to an additional annual income inflow of about 5 billion US\$ (in 2010). Given the importance of rice for agricultural production, employment and food budget shares, the gains from GM rice adoption are orders of magnitude larger than the Bt cotton gains. The estimated macro economic welfare gains far outweigh the public biotechnology research expenditures. Although the productivity gains for China are significant and translate to rising exports or reducing imports, the patterns of global trade in agriculture are not affected very much.

Despite the success and the potential success of China at the farm level, the institutional framework for supporting agricultural biotechnology research program is complex and evolving both at national and local levels. The growth of government investment in agricultural biotechnology research in China has been remarkable. There has also been significant improvement of the level of human resources that are working on agricultural biotechnology. Examination of the research foci of agricultural biotechnology research reveals that food security objectives and the demands by farmers for specific traits and crops are being incorporated into the technologies that are being given priority by the research system. 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. Our review of agricultural biotechnology R&D does not show any significant constraints in the national government's ability and willingness to continue to fund agricultural

biotechnology R&D. However, there are outstanding issues. For example, there needs to be better coordination among institutions and perhaps a series of strategic consolidations of China's agricultural biotechnology programs. Important decisions need to be made also that will encourage (or continue to discourage) the participation of domestic private and foreign in the agricultural biotechnology sector.

Our study also shows that China is developing one of the most comprehensive agricultural GMO biosafety regulatory systems in the developing world. Beside the national GMO biosafety rgulation system, China also has established a series of subnational agricultural biosafety regulatory office in nearly all provinces. Investment in the biosafety system has increased rapidly in recent years. The system of biosafety regulation has become progressively more comprehensive and sophisticated. Our statistical analysis shows that Bt cotton varieties that have been approved by the biosafety committee actually performed better than varieties that were not approved, which implies that enforcing biosafety regulations could have substantial positive impact on farmers. The results also imply that poor regulations are slowing the adoption of high quality Bt cotton and reducing economic welfare. The costs to farmers of better enforcement of regulations need to be carefully weighed against the future possible benefits from such as pest susceptibility to Bt. Our results also show that the enforcement of biosafety regulations can be a substitute for formal intellectual property rights. If the government really eliminated the use of unapproved varieties and only allowed approved varieties into those areas, the government would essentially be establishing a duopoly for CAAS and MDP. .

Review of agricultural GMO biosafety implementation, however, shows that the enforcement is not without problems. The important caveat is that government investments in regulation of biotechnology, although rising significantly recently, will have to be further increased to ensure that regulations can be enforced and effectively implemented. The current level of investment in both biosafety research and regulatory management are not sufficient. Investment should focus more on the monitoring GM crop production and varietal breeding both before and after its commercialization. There should be a clear division of and sufficient funding for GMO biosafety assessments.

Reviews of IPR legislation and seed industry reforms show that the environment for commercialization has been improving, particular in the recent years. Domestic firms in China and international seed firms have started to invest in the seed industry in response to a new seed law and changes in regulations. The combination of these changes, along with the development of the nation's agricultural biosafety regulatory system, has led to greater investments by commercial seed firms in developing and spreading new varieties than in the past. However, it is important to note that these investments—even with the recent progesess—are still small compared to that of OECD countries (Pray and Fuglie 2001).

China's environment of IPR is also in flux. Our regression analysis shows that that the legitimate seed from seed companies associated with CAAS and MDP provides more benefits to farmers than Bt seed that was not from authorized CAAS or MDP dealers. Such results imply that stronger IPRs could increase the benefits to farmers at the same time that they increase the profits of seed companies and royalties to innovators. In addition these changes could have positive dynamic affects in providing incentives for biotech companies to do more research and develop new technology for the future.

Finally, seed from seed companies also gave better returns than varieties from government agencies, which suggests it might be time to close some of the traditional SOE seed operations down and promote reform. In other words, more privatization may be beneficial to farmers. It is interesting to note that the Bt seed from seed companies had some advantage over farmer saved seed, but if farmers did not have the needed cash to buy seed, they could still get far superior performance from saved Bt seed than by reverting to conventional cotton varieties.

In short, in this paper we have tried to give a comprehensive assessment of China's agricultural biotechnology program. Indeed, the progress it has achieved is one of the remarkable achievements of China—and of any developing country—in the last part of the 20th century and in the first part of the 21st century. The experience of China has shown small, poor farmers can benefit—and have benefits in many different dimensions—from GM crops. However, setting up and running a sustainable, safe and efficient GM breeding and production program is not easy. The investments required into institutions and R&D and production are immense and require time to develop. Certainly, China's progress in almost all dimension is admirable and holds lessons for other developing countries. It also still has a long ways to go, however. The weaknesses and attempts to overcome the shortcomings, however, also contain many lessons for nations that seek to build a modern agricultural biotechnology system.

References

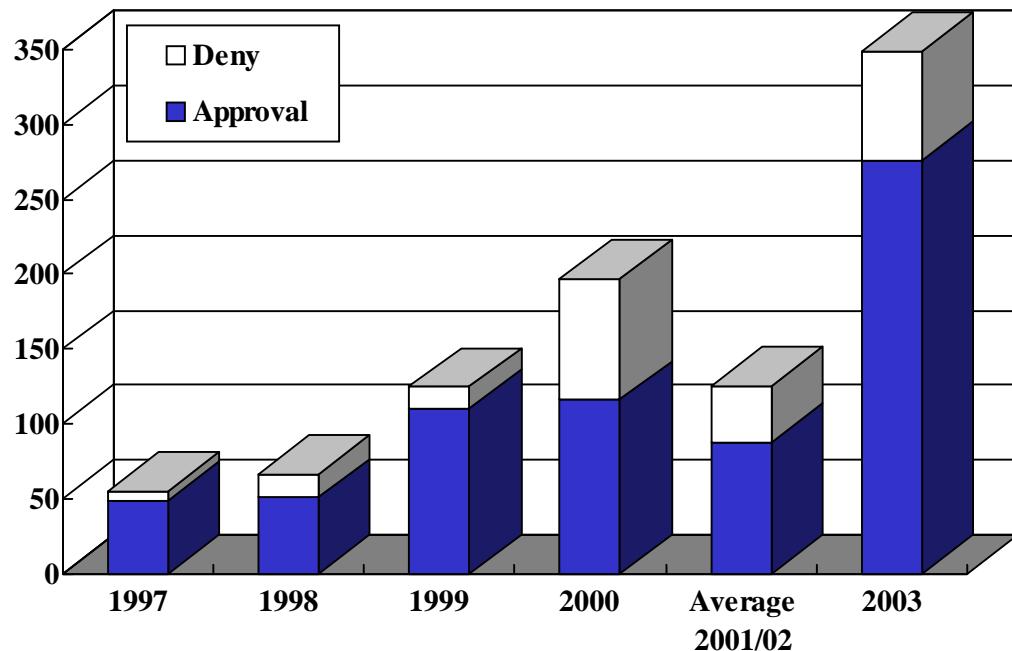
- Anderson, Kym, Shunli Yao. 2003. China, GMOs and world trade in agricultural and textile products, *Pacific Economic Review*, Vol.8 . No.2 [June 2003]: 157-169.
- BRI [Biotechnology Research Institute]. 2000. Research achievements of biotechnology. Working Paper, BRI, Chinese Academy of Agricultural Sciences.
- Cheng, Jingen and Yufa Peng, (2002). Biosafety regulation in China, paper presented at the 7th International Symposium on the *Biosafety of Genetically Modified Organisms*, Beijing, China, October 10-16, 2002.
- Cheng, Z, X He, and C. Chen. (1997). Transgenic wheat plants resistant to barley yellow dwarf virus obtained by pollen tube pathway-mediated transformation. Chinese Agricultural Science for the Compliments to the 40th Anniversary of the Chinese Academy of Agricultural Science, *China Agricultural SciTech Press*, 98-108.
- Genetic Resources Action International (GRAIN; 2001). “Bt Cotton through the back door,” *Seedling*, Volume 18, Issue 4, December 2001, GRAIN Publications downloaded from www.grain.org/publications/seed-01-12-2-en.cfm April 21, 2002.
- Fang Xuanjun, Cheng Daxin, Xu Jun, Xu Rongqi, and Fan Tianshu. 2001“Commercial implementation of intellectual property rights of Chinese transgenic insect resistant cotton with *Bt* gene and *Bt+CpTI* genes” *Journal of Agricultural Biotechnology* 2001, 9 (2): 103–106
- Headley, J.C. 1968. Estimating the Productivity of Agricultural Pesticides. *American Journal of Agricultural Economics*, vol. 50, pp. 13-23.
- Hertel, T.W. (ed). 1997. Global Trade Analysis: Modelling and Applications, Cambridge University Press.
- Hu, Ruifa. Carl Pray, Jikun Huang, Scott Rozelle, Cunhui Fan and Caiping Zhang. 2005. Intellectual Property, Seed and Biosafety: Who Could Benefit from Policy Reform?” Working Paper, Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing.
- Huang, Dafang. 2002. Research and development of recombinant microbial agents and biosafety consideration in China. Paper presented at the 7th International Symposium on the *Biosafety of Genetically Modified Organisms*, Beijing, China, October 10-16, 2002.
- Huang, Jikun, Ruifa Hu, Cuihui Fan, Carl E. Pray and Scott Rozelle, 2003a. “Bt Cotton Benefits, Costs, and Impacts in China,” *AgBioForum*, 5(3) 2003: 1-14.
- Huang, Jikun, Ruifa Hu , Hans van Meijl, and Frank van Tongeren. 2004.“Biotechnology Boosts to Crop Productivity in China: Trade and Welfare

- Implications," *Journal of Development Economics*, Vol.75(2004):27-54.
- Huang, Jikun, Ruifa Hu, Carl Pray, Fangbin Qiao, and Scott Rozelle, 2003b. "Biotechnology as an Alternative to Chemical Pesticides: A Case Study of Bt Cotton in China" *Agricultural Economics*, 29(2003) 55-67.
- Huang, Jikun, Ruifa Hu, and Scott Rozelle. 2003. Agricultural Research Investment in China: Challenges and Prospects. China's Finance and Economy Press, Beijing.
- Huang, Jikun, Ruifa Hu, Scott Rozelle, and Carl Pray. 2005a. "GM Rice in Farmer Fields: Assessing Productivity and Health Effects in China," *Science*, 29 April 2005 Vol. 308: 688-690.
- Huang, Jikun, Ruifa Hu, Scott Rozelle, Fangbin Qiao, and Carl Pray. 2002b. "Transgenic Varieties and Productivity of Smallholder Cotton Farmers in China," *Australian Journal of Agricultural and Resource Economics*, 46:3, (2002): 367-387.
- Huang, Jikun, Ruifa Hu, Huanzhu Zhang, Carl Pray, and Jose Falck-Zepeda. 2005b. "GMO Biosafety Management and Regulatory Costs: A Case Study in China. Working Paper, Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing.
- Huang, Jikun, Ninghui Li and Scott Rozelle, 2003. "Trade Reform, Household Effect, and Poverty in Rural China," *American Journal of Agricultural Economics*. 85 □Number 5, 2003□:1292-1298.
- Huang, Jikun, Fangbin Qiao, Linxiu Zhang and Scott Rozelle, 2000. "Farm Pesticide, Rice Production, and the environment" *EEPSEA Research Report 2001-RR3*. IDRC, Singapore.
- Huang, Jikun, Scott Rozelle, and Carl Pray. 2002c. "Enhancing the Crops to Feed the Poor," *Nature*, Vol. 418, 8 August 2002: 678-684.
- Huang, Jikun, Scott Rozelle, Carl Pray, and Qingfang Wang. 2002a. "Plant Biotechnology in China," *Science*, Vol. 295, 25 January 2002: 674-677.
- Huang, Jikun and Qinfang Wang, 2003. "Agricultural Biotechnology Development and Policy in China," *AgBioForum*, 5(3) 2003:1-15.
- Huang, J., Q. Wang, Y. Zhang and J. Zepeda. (2001). Agricultural biotechnology development and research capacity in China. Working Paper, *Center for Chinese Agricultural Policy, Chinese Academy of Sciences*.
- Hossain, Ferdaus, Carl. E. Pray, Yanmei. Lu, Jikun Huang, Cunhui Fan, Ruifa Hu. "GM cotton and farmer's health in China: an econometric analysis of the relationship between pesticide poisoning and GM cotton use in China," *International Journal of Occupational and Environmental Health*. Vol.10(2004) pp 307-314.
- Hsu, H. and Gale, F. (2001). "Regional shifts in China's cotton production and use" in *Cotton and Wool Situation and Outlook*. Economic Research Service-U.S.

- Department of Agriculture: Washington DC, November 2001.
- Ismael, Y., Thirtle, C. and Beyers L. with Bennett, R., Morse, S., Kirsten, J., Gouse, M., Lin, L., Piesse, J. (2001). "Smallholder adoption and economic impacts of *Bt* cotton in the Makhathini Flats, Republic of South Africa." A Report for DFID Natural Resources Policy Research Programme Project R7946. London, U.K.
- Li, N. 2000. Review on safety administration implementation regulation on agricultural biological genetic engineering in China. A Paper Presented at the *China-ASEAN Workshop on Transgenic Plants*, July 30-August 5, Beijing, China.
- Lichtenberg, E. and Zilberman, D. 1986. The econometrics of damage control: why specification matters. *American Journal Agricultural Economics*, vol. 68, pp. 261-273.
- MOA [Ministry of Agriculture]. 1990. The guideline for the development of science and technology in middle and long terms: 1990-2000.
- MOA [Ministry of Agriculture]. 1999. The application and approval on agricultural biological genetic modified organisms and its products safety. Administrative Office on Agricultural Biological Genetic Engineering, No.4 pp:35-37.
- MOA [Ministry of Agriculture], Agricultural GMO Biosafety Management Office. 2005. www.stee.agri.org.cn.
- MOST [Ministry of Science and Technology]. 1990. Biotechnology development policy. China S&T Press, Beijing.
- MOST [Ministry of Science and Technology]. 2000. Biotechnology development outline.
- NCBED [National Center of Biological Engineering Development]. 2000. The research progress in biotechnology. *Biological Engineering Progress*, Vol. 20, Special Issue.
- NSBC [National Statistical Bureau of China]. 2003. Statistical Yearbook of China. China's Statistical Press, Beijing.
- Nyberg, A. and S. Rozelle. 1999. Accelerating China's Rural Transformation. the World Bank, Washington DC.
- Peng, Yufa. 2002. "Strategic approaches to biosafety studies in China. Paper presented at the 7th International Symposium on the *Biosafety of Genetically Modified Organisms*, Beijing, China, October 10-16, 2002.
- Pray, Carl E. and Keith O. Fuglie. Private Investments in Agricultural Research and International Technology Transfer in Asia *ERS Agricultural Economics Report No. 805*. November 2001. <http://www.ers.usda.gov/publications/aer805/>
- Pray, Carl, Danmeng Ma, Jikun Huang and Fangbin Qiao. 2001. "Impact of Bt Cotton in China," *World Development*, Vo1.29(2001):813-825.
- Pray, Carl, Jikun Huang, Ruifa Hu, and Scott Rozelle. 2002. "Five Years of Bt Cotton

- in China: the Benefits Continue," *The Plant Journal*, (2002) 31(4): 423-430.
- Qaim, M. and D. Zilberman. 2003. "Yield Effects of Genetically Modified Crops in Developing Countries," *Science*, 299(5608): 900-902.
- SDPC [State Development and Planning Commission]. 2003. Development of Biotechnology Industry in China –2002. Chemical Industry Press, Beijing.
- SSTC [State Science and Technology Commission]. 1990. Development Policy of Biotechnology, The Press of Science and Technology.
- Traxler, G., Godoy-Avila, S., Falck-Zepeda, J., and Espinoza-Arellano, J.J. (2001). Transgenic cotton in Mexico: economic and environmental impacts. Unpublished report. Department of Agricultural Economics, Auburn University. Auburn, Alabama.
- Yu, J., S. Hu, J. Wang, G.K.S. Wong, S. Li, B. Liu, Y. Deng, L. Dai, Y. Zhou, X. Zhang, M. Cao, J. Liu, J. Sun, J. Tang, Y. Chen, X. Huang, W. Lin, C. Ye, W. Tong, et al. (2002). A draft sequence of the rice genome (*Oryza sativa* L. ssp. Indica), *Science*, 296(5565):79-108.
- Zhang, X., J. Liu, and Q. Zhao. 1999. Transfer of high lysine-rich gene into maize by microprojectile bombardment and detection of transgenic plants." *Journal of Agricultural Biotechnology*, Vol.7, No.4 pp: 363-367.

Figure 1. Cases of Agricultural Biosafety Assessments (field trials, pre-productions and commercialization) in China, 1997-2003



Source: Huang et al., 2005b.

Table 1. Research focus of plant biotechnology programs in China.

Crops/traits	Prioritized areas
Crops	Cotton, rice, wheat, maize, soybean, potato, rapeseed, Cabbage, tomato
Traits	
Insect resistance	Cotton bollworm, boll weevil and aphids Rice stem borer Wheat aphids Maize stem borer Soybean moth Potato beetle Poplar Gypsy moth
Disease resistance	Rice bacteria blight and blast Cotton fungal disease Cotton yellow dwarf Wheat yellow dwarf and rust Soybean cyst nematode Potato bacteria wilt Rapeseed sclerosis
Stress tolerance	Drought, salinity, cold
Quality improvement	Cotton fiber quality Rice cooking quality Wheat quality Maize quality Corn with phytase or high lysine
Herbicide resistance	Rice, soybean
Functional genomics	Rice, rapeseed Arabidopsis

Source: Huang and Wang, 2003 .

Table 2. Bt cotton adoption in China, 1997-2001.

Year	Cotton area (000ha)		Bt cotton share (%)	Source (%)	
	Total	Bt cotton		CAAS	Monsanto
1997	4491	34	1	48	52
1998	4459	261	6	20	80
1999	3726	654	18	16	84
2000	4041	1216	30	22	78
2001	4810	2158	45	33	67
2002	4184	2156	52	40	60
2003	5111	2996	59	50	50
2004	5650	3688	65	61	39

Source: Authors' survey.

Table 3. 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						
<i>Bt</i>	124	120	91	3197	3244	3510
Non- <i>Bt</i>	0	0	0	na	na	na
Shandong						
<i>Bt</i>	213	238	114	3472	3191	3842
Non- <i>Bt</i>	45	0	0	3186	na	na
Henan						
<i>Bt</i>		136	116		2237	2811
Non- <i>Bt</i>		122	42		1901	2634
Anhui						
<i>Bt</i>			130			3380
Non- <i>Bt</i>			105			3151
Jiangsu						
<i>Bt</i>			91			4051
Non- <i>Bt</i>			29			3820
All samples						
<i>Bt</i>	337	494	542	3371	2941	3481
Non- <i>Bt</i>	45	122	176	3186	1901	3138

Note: Cotton production in Henan was seriously 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: Huang et al., 2003a and Pray et al., 2002.

Table 4. 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: Huang et al., 2003a and Pray et al., 2002.

Table 5. Impact of *Bt* on farmer poisoning, 1999-2001.

		Farmers planting non- <i>Bt</i> cotton only	Farmers planting both <i>Bt</i> and non- <i>Bt</i> cotton	Farmers planting <i>Bt</i> 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.

Sources: Huang et al., 2003a and Pray et al., 2002.

Table 6. 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	
		Cobb-Douglas function	Exponential damage control function
Perception of <i>Yield loss</i> (%):	0.135 (0.03)***		
Average pesticide <i>Price</i> (yuan/kg)	-0.133 (0.03)***		
<i>Farm size</i> (ha)	-13.259 (3.38)***		
Household characteristics:			
<i>Age</i> (years)	0.016 (0.07)	-0.033 (0.05)	-0.030 (0.06)
<i>Education</i> (years)	-1.302 (0.28)***	-0.005 (0.01)	-0.001 (0.01)
<i>Village leader dummy</i>	1.336 (2.25)	0.074 (0.04)*	0.073 (0.04)*
<i>Bt cotton training dummy</i>	-2.717 (1.49) *	0.032 (0.03)	0.029 (0.03)
Conventional inputs:			
<i>Labor input</i> (Days/ha)		0.02 (0.04)	0.033 (0.04)
<i>Fertilizer</i> (kg/ha)		0.107 (0.02)***	0.126 (0.02)***
<i>Other inputs</i> (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)
<i>Bt cotton Variety dummy</i> (<i>Bt</i>)	-43.246 (4.03)***	0.083 (0.04)**	0.096 (0.03)***
<i>Bt x T2000</i>	12.60 (4.93)***		
<i>Bt x T2001</i>	10.33 (4.66)**		
Predicted <i>Pesticide use</i> (kg/ha)		-0.021 (0.02)	
Damage control parameter estimates			0.593
<i>c</i> (pesticide parameter)			(0.29)**
<i>c₁</i> (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. Sources: Huang et al., 2003a.

Table 7. Pesticide use and yields of insect-resistant GM rice adopters and non-adopters in pre-production trials in China, 2002-2003.

	Adopters of insect-resistant GM rice		Non-GM rice (Non-adopters)	
	Mean	Standard deviation	Mean	Standard deviation
Pesticide spray (times)	0.50	0.81	3.70	1.91
Expenditure on pesticide (yuan/ha)	31	49	243	185
Pesticide use (kg/ha)	2.0	2.8	21.2	15.6
Pesticide spray labor (days/ha)	0.73	1.50	9.10	7.73
Yield (kg/ha)	6364	1294	6151	1517
Number of observations (plots)	123		224	

Source: Huang et al., 2005a.

Table 8. The effect of insect-resistant GM rice use on the health of farmers in sample pre-production village sites in China, 2002 and 2003.

	Full adopters:		Partial adopters:		Non-adopters:
	Planted GM rice <i>only</i>	Planted <i>both</i> GM and non-GM rice	GM plot	Non-GM Plot	Planted <i>non-GM rice only</i>
2002	0.0	0.0	7.7		8.3
2003	0.0	0.0	10.9		3.0

Note: Table reports the share of households who reported having adverse health effects after spraying.

Source: Huang et al. (2005a).

Table 9. Estimated parameters using household fixed effects model for estimating effect of insect-resistant GM rice varieties on farmers' pesticide application and yield of households in pre-production trials in China.

Variables	Pesticide use (kg/ha)		Yields (kg/ha) in log	
	Model I	Model II	Model I	Model II
Intercept	19.93 (1.17)***	19.78 (1.32)***	7.55 (0.50)***	7.61 (0.51)***
Variety dummies (base=other non-GM varieties)				
GM rice, both varieties	-16.77 (1.28)***		0.06 (0.03)*	
Variety-specific dummy variables				
GM Xianyou 63		-17.15 (2.60)***		0.09 (0.05)*
GM II-Youming 86		-25.33 (5.48)***		0.02 (0.10)
Non-GM Xianyou 63		1.04 (2.61)		-0.03 (0.05)
Non-GM II-Youming 86		-1.25 (3.82)		0.07 (0.07)
Control Variables				
Pesticide price (yuan/kg)	-0.02 (0.03)	-0.02 (0.03)		
Natural disaster dummy (affected=1)	8.56 (2.65)***	8.65 (2.65)***	-0.51 (0.05)***	-0.51 (0.05)***
2003 year dummy	-0.17 (1.20)	-0.01 (1.24)	-0.05 (0.02)**	-0.05 (0.02)**
Labor (log)			0.17 (0.07)**	0.17 (0.07)**
Fertilizer (log)			0.04 (0.06)	0.03 (0.06)
Machine (log)			0.00 (0.01)	0.00 (0.01)
Other inputs (log)			0.03 (0.04)	0.02 (0.04)
Pesticides (log)			0.00 (0.00)	0.00 (0.00)
Household Dummy Variables	Included but not reported			
Number of observations	347	347	347	347

Note: The coefficients from the multiple regression model represent the net effect of insect-resistant GM rice varieties on pesticide use and yield, holding the other plot-varying variables in the model constant. The use of household fixed effects is accomplished by including 108 household dummy variables (equals 1 for the household and zero otherwise), which allows for the control for all unobserved non-time varying producer and farm characteristics. Parameters in the parentheses are standard errors. The symbols, ***, ** and *, denote significance at 1%, 5% and 10%, respectively. Data: authors' survey.

Source: Huang et al., 2005a.

Table 10. Main sectoral effects of adopting Bt cotton (percent change, relative to situation without Bt cotton in 2010)

	Total impact	Yield increasing	Labor saving	Pesticide saving	Higher seed price
Cotton					
Supply price	-10.9	-7	-3.3	-1.7	1.1
Output	4.9	3.1	1.5	0.8	-0.5
Dom demand	4.8	3	1.5	0.8	-0.5
Exports	58	37.3	17.5	9	-5.8
Imports	-16.6	-10.8	-4.9	-2.5	3.1
Trade balance (million USD)	389	253	114	59	-71
Textiles					
Supply price	-0.3	-0.2	-0.1	0	0
Output	0.7	0.4	0.2	0.1	0
Exports	0.9	0.6	0.3	0.1	0
Imports	-0.3	-0.2	-0.1	0	0
Trade balance (million USD)	1067	670	341	155	-41

Note: Bt cotton adoption rate is assumed to be 92% in 2010.

Source: Huang et al. (2004).

Table 11. Impacts of adopting Bt cotton and GM rice (percent change, relative to situation without GM products in 2010)

	Total impact Bt cotton & GM rice	Total impact GM rice	Yield increase	Labor saving	Pesticide saving	Higher seed price
Rice (%)						
Supply price	-12.0	-12.1	-7.8	-4.4	-0.9	1.1
Output	1.4	1.4	0.9	0.6	0.1	-0.1
Dom demand	1.1	1.1	0.7	0.4	0.1	-0.1
Exports	66.9	66.2	43.5	24.1	5.2	-5.8
Imports	-23.2	-23.4	-15.3	-8.4	-1.8	2.1
Change rice trade balance (million USD)	173.2	175.1	113.8	63.1	13.7	-15.5
Welfare (EV, million USD)	5249	4155				

Note: GM rice adoption rate is assumed to reach 95% in 2010.

Source: Huang et al. (2005).

Table 12. Results of sensitivity analysis: adoption of Bt cotton and GM rice

	Adoption rates: Cotton:92%; Rice:95 %		Adoption rates: Cotton: 56%; Rice: 56%	
	Total Impact	Total impact	SSA Mean*	SSA Standard deviation*
Cotton				
Supply price	-10.9	-7.2	-7.3	1.2
Output	4.9	3.2	3.2	0.5
Exports	58	35	34.9	6.7
Imports	-16.6	-11.1	-11.2	1.8
Trade balance	389	260	261	43
Rice				
Supply price	-12	-7.5	-7.5	1.3
Output	1.4	0.8	0.8	0.2
Exports	66.9	36.6	36.5	7.6
Imports	-23.2	-14.7	-14.9	2.6
Trade balance	173	101	101	19.5
EV	5249	3280	3289	939
EV/sectoral value added**	15.1	9.4	9.5	2.7

Note: Systematic sensitivity analyses in 56% scenario around cotton and rice productivity shocks (vary 60%, triangular distribution). EV is equivalent variation measured in million USD as a percentage of sectoral value added from rice and cotton sector (measured in million USD).

Source: Huang et al. (2004).

Table 13. Research staff in agricultural biotechnology in China, 1986-2003

	Total	Plant	Animal	Micro-organism
All staff				
1986	1436	917	378	142
1990	2189	1271	691	227
1995	2918	1750	873	295
2000	4502	2545	1476	481
2003	5772	3125	1901	746
Professional staff				
1986	667	391	217	60
1990	1060	615	335	110
1995	1561	936	467	158
2000	2470	1396	809	264
2003	3203	1735	1055	413

Source: Authors' survey.

Table 14. Public expenditures on agricultural biotechnology in China, 1986-2003

	Total	Plant	Animal	Micro-organism
Million RMB in real 2003 prices				
1986	89	51	28	10
1990	204	118	64	23
1995	273	157	86	30
2000	861	450	323	88
2003	1647	996	468	183
Million USD converted at official exchange rates				
1986	10	6	3	1
1990	25	15	8	3
1995	33	19	10	4
2000	104	54	39	11
2003	199	120	57	22
Million donors converted at PPP				
2003	953	576	271	106

Note: expenditures include both project grants and costs related to equipment and buildings. Official exchange rate in the corresponding year is used to convert the domestic currency to US dollars in at current price. Official change rate was 8.277 RMB/US\$ and the converting rate of RMB to donors in PPP was 1.729 in 2003.

Table 15. Major policy measures related to agricultural biosafety regulation in China.

The MOST Biosafety regulation in 1993	MOST issued “the Measures for the Safety Administration of Genetic Engineering” in December 1993, which includes the biosafety categories and safety assessment, application and approval procedure, safety control measures, and legal regulations. The Measure provides a framework for each sub-sector to develop its own detail regulation and implementation.
The First MOA's Agri. biosafety management regulation in 1996	Based on MOST's 1993 Measure, MOA issued “the Implementation Measures for the Safety Control of Agricultural Organism Genetic Engineering” in July 1996. It covers the plant, animal and microorganism.
Agri GMO Biosafety Committee in 1997	Ministry level Agricultural GMO Biosafety Committee was set up in MOA in 1997. The Committee was updated in 2002 to national level with its office in MOA.
The State Council Agri biosafety regulation in 2001	The State Council amended MOA 1996 agricultural biosafety regulation to include trade and labeling of GM farm products and issued the new regulation, “Regulation on the Safety Administration of Agricultural Transgenic Organisms,” which has been in effective after May 23, 2001.
The Second MOA's Agri biosafety management regulation in 2002	Based on the State Council's 2001 Regulation, MOA amended its 1996 biosafety implementation regulation and issued 3 independent ones effective after March 20, 2002. They are “Measures for Management of the Evaluation on the Safety of Agricultural Transgenic Organism,” “Measures on Safety Administration of Agricultural Transgenic Organism Import,” and “Measures on the Labeling Administration of Agricultural Transgenic Organism”.
The Regulation on GMO food hygiene	In April 2002, MOH (Ministry of Health) issued the management regulation on GMO food hygiene, which requires that the foods and processed food using GMOs as materials must be approved by MOH before selling in the markets and GMO foods must be labeled.
Regulations on regional variety test of GM crops	In July 2004, MOA issued a policy to enhance the management of GM varieties, which requires that any new developed GM varieties must have their safety certificates from MOA when the varieties are applied for regional variety trials. For any cotton varieties, the applicants must present a certificate of GM or non-GM varieties through MOA designated testing institutes/organizations that conducted gene test.
Regulation on GM commercialization scale based on the ecologic region	In September 2004, MOA issued policies to simplify regulation procedure on bt cotton's commercialization by several measures: 1) any bt cotton variety (including variety line) received a production safety certification (or commercialization) from one province can directly apply for the safety certificates in the rest of provinces within same cotton-ecological regions (3 regions only in China); 2) any bt cotton variety (including variety line) received a production safety certification (or commercialization) from any region can directly apply for the safety certificates in one provinces in other regions; 3) any variety (or variety line) can directly apply for safety certificate in one province if the variety (or variety line) is back-crossed based on the variety (or variety line) with the safety certificate.

Table 16. Estimated government budgetary allocations on agricultural biosafety research and regulation implementation.

	Biosafety research budgets (million RMB)	Biosafety administrative budget (million RMB)	Total biosafety budget (million RMB) (c)=a+b	Total biosafety budget (million US\$)	As share of biotech research budget (%)
1997	0.45	0.56	1.01	0.12	0.23
1998	0.58	0.60	1.18	0.14	0.20
1999	0.72	0.66	1.38	0.17	0.16
2000	1.71	0.70	2.41	0.29	0.28
2001	8.69	0.77	9.46	1.14	0.82
2002	11.68	3.38	15.06	1.82	1.11
2003	17.92	5.46	23.38	2.83	1.44
2004	18.64	5.52	24.16	2.92	NA

Note: budgets are deflated by CPI and in 2000 constant prices. The total government expenditure on agricultural biotechnology is from a recent CCAP survey of agricultural biotechnology institutes and administrative agencies.

Source: Huang et al. (2005b)

Table 17. Estimated parameters for pesticide use and cotton yield

	Pesticide Use (kg/ha)	Cotton Yield (Exponential damage control function)
Intercept	51.106 (5.95)***	5.994 (0.31)***
Perception of <i>Yield loss</i> (%):	0.156 (0.03)***	
Average pesticide <i>Price</i> (yuan/kg)	-0.326 (0.04)***	
Household characteristics:	0.009	-0.034
<i>Age</i> (years)	(0.07)	(0.06)
<i>Education</i> (years)	-1.263 (0.28)***	0.002 (0.01)
<i>Village leader dummy</i>	0.869 (2.24)	0.079 (0.04)*
<i>Bt cotton training dummy</i>	-2.28 (1.49)	0.021 (0.03)
Farm size scale (ha)	-14.128 (3.40)***	
Conventional inputs:		0.031
<i>Labor input</i> (Days/ha)		(0.04)
<i>Fertilizer</i> (kg/ha)		0.127 (0.02)***
<i>Other inputs</i> (yuan/ha)		0.159 (0.01)***
Bt seed sources:		
<i>Seed company</i> :		
<i>Legitimate MDP</i>	-39.770 (2.52)***	0.257 0.05***
<i>Illegitimate MDP</i>	-30.567 (2.49)**	0.128 0.05***
<i>Legitimate CAAS</i>	-41.447 (3.79)***	0.192 0.07***
<i>Illegitimate CAAS</i>	-33.515 (2.75)***	0.012 0.05
<i>Unapproved</i>	-38.530 (3.85)***	0.082 0.07
<i>Traditional channels</i> :		
<i>Ag Extension Station</i>	-34.683 (2.71)***	-0.004 0.05
<i>Cotton office</i>	-30.188 (3.43)***	-0.013 0.06
<i>Self-saved</i>	-33.293 (2.39)***	0.153 0.05***
<i>Ginning factory</i>	-34.881 (3.77)***	0.200 0.07***
Coated seed dummy	-0.314 (2.46)	0.009 (0.05)
Hybrid seed dummy	14.123 (6.40)***	0.060 (0.04)
Year dummies	14.004	0.129
<i>T2000</i>	(2.39)***	(0.04)***
<i>T2001</i>	12.008 (2.69)***	0.362 (0.04)***
Damage control parameter estimates		0.658
<i>C</i> (pesticide parameter)		(0.37)**
<i>C_j</i> (Bt variety parameter)		3.540 (0.73)***

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

