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Institutional Constraints for the Success

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The Case of Bt-Cotton in Shandong Province, China

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Abstract. The use of genetically engineered crop varieties has recently become one option to prevent pest damage in agriculture. The promoters of biotechnology stress the great potential for yield increase and pesticide reduction while the critics point out the potential risks for biodiversity and human health as well as institutional problems for implementation especially in developing countries. The objective of this paper is an in-depth economic analysis of Bt-cotton production in North East China under small-scale conditions and several years after technology introduction. Data were collected in 2002 (March - October) in Linqing County, a major cotton growing area of Shandong Province, China. Data collection comprised a season-long monitoring of Bt-cotton production with 150 farmers from five villages, and three complementary household interviews. In addition, plot-level biological testing was carried out to determine the actual Bt toxin concentration in the varieties that were used by the farmers. All farmers in the case study were growing insect resistant Bt-cotton varieties in 2002. Nevertheless, they sprayed high amounts of chemical pesticides that were almost entirely insecticides. A proportion of 40% of the pesticides applied belonged to the categories *extremely* or *highly hazardous* (WHO classes Ia and Ib). The paper reviews methodological issues inherent to impact assessment of crop biotechnology and identifies market and institutional failure as possible reasons for continued high pesticide use. The production function methodology with damage control function was applied and it was found that for both damage control inputs, i.e. Bt and insecticides the coefficients were not significantly different from zero. In contrast to studies that treat Bt varieties as dummy variable in economic models, in this research it was possible to specify Bt toxin concentration in cotton leaf samples as a continuous variable. The results of this study support the notion that introducing Biotechnology in developing countries without enabling institutions that assure proper use of the technology can considerably limit its benefits. Hence it is important to

include institutional criteria in the evaluation of agricultural biotechnology especially in developing countries.

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Institutional Constraints for the Success of Agricultural Biotechnology in Developing Countries: The Case of Bt-Cotton in Shandong Province, China

1. INTRODUCTION

The discussion of whether modern biotechnology[1] can help agriculture in developing countries to overcome some of its most pressing problems is controversial. The promoters of biotechnology stress the great potential for yield increase and pesticide reduction while the critics point out the potential risks for biodiversity and human health as well as institutional problems for implementation. To put this debate into perspective it needs to be pointed out that currently, on a global scale, only a small share of about 1.5% of the crop land[2] is planted to transgenic crops, of which an estimated two thirds in industrialized countries. Over 99% of today's agricultural biotechnology products are in pest management with 70% in the form of herbicide tolerance and the remainder being insect resistance in the form of Bt crops, namely cotton and corn. Among the developing countries China is the only one that has introduced Bt cotton on a large scale. In 2004 an estimated 3.7 million hectare or about 65% of the national cotton area were planted with Bt varieties (James 2004).

Since commercial approval of biotechnology products is granted by province, diffusion shows a distinct regional distribution. For example, Bt cotton has spread rapidly in North and East China while in some provinces in Southern China these varieties are not grown at all or to a much lesser extend. Two years after the introduction of Bt cotton varieties in China in 1997 economists have carried out impact assessment studies (Pray *et al*. 2001; Pray *et al*. 2002). These studies, which compared farmers growing Bt cotton with those growing conventional varieties, found that Bt varieties reduced the quantity of chemical pesticides by around 80%, with 67% fewer sprays and an 82% reduction in pesticide costs (Huang *et al*. 2002).

Reduction of toxic chemical pesticides in developing country agriculture is an important development issue especially in view of their negative effects on the health status of the rural population (Rola and Pingali 1993; Crissman *et al*. 1994; Antle and Capalbo 1994; Pingali *et al.* 1994). Hence, the benefits of Bt crops to a large extent depend on their potential to reduce external costs by substituting chemical pesticides. In China yield increase due to Bt cotton is minor since yields are generally very high (Pray *et al*. 2002).

When looking at the methodology of past impact studies (e. g. Pray *et al*. 2002) a number of factors can be found that could have pre-determined the unanimously positive results. For example, one common problem is the reference group used to measure the impact of the Bt system. The concept was to follow the path of Bt introduction by province over a period of three years and interviewing adopters and non-adopters in old and new provinces. No baseline data were collected that could have shown whether adopters and non-adopters had similar socioeconomic conditions before Bt introduction. Thus the classic "difference in difference model" that is required for good impact assessment was not applied. One consequence of the procedure used in past impact assessments of Bt cotton in China was that non-adopters were "lost" in the provinces of previous introduction during later years. As a result, the sample size for adopters by far exceeded those of non-adopters. This can perhaps explain why, on average, non-adopters had negative net returns from cotton production in all three years of the study (Figure 1). Another weakness of using non-adopters as counterfactual is that they may not have adopted Bt crops because they did not find it profitable for their circumstances.

Insert Figure 1 here

A second factor that deserves close scrutiny is the data collection protocol used in impact studies. Since the economic benefits of Bt cotton are mainly determined by pesticide reduction, accurate measurement of these inputs is critical. Among all crop production inputs chemical pesticides are among the most difficult to quantify especially under the conditions of developing countries. High frequency of applications with a large number of different product names and mixtures of different products make it extremely difficult to measure pesticide quantity especially by recall surveys. Also, the practice of spot treatments poses a source of error when farmers do not keep records and when data are collected months after pesticide application has taken place.

Finally, a question that emerges from previous studies is that regardless of whether farmers use Bt or non-Bt varieties the actual level of pesticide use dramatically exceeded its economically optimal level as computed from estimated factor productivity (Huang *et al.* 2002). The authors attribute this overuse to anecdotic evidence about misguided extension advice. Since part of the income of extension workers stems from pesticide sales they have an incentive to encourage farmers to use more pesticides than necessary. In a recent study Yang *et al.* (2005) found, that the use of pesticides in Bt cotton production in Shandong Province was on average 12.7 applications and average amounts of 18.9 kg per hectare. A majority of farmers still considered the cotton bollworm as a problem although all were using Bt-cotton. Such observations show that although the economic benefits of Bt cotton in China were demonstrated at an early stage of adoption, the sustainability of these benefits can be questioned. They also indicate that pesticide reduction requires other (supplementary) means such as a policy change.

The prevailing institutional conditions are crucial to the realization of potential benefits of new technologies especially those aiming at pesticide use reduction of other inputs. The lessons learned from the introduction of integrated pest management (IPM) that showed high benefits in experiments and pilot projects are that institutional as well as socio-economic and technical constraints can considerably limit farm-level benefits and even prevent technology adoption (Beckmann and Wesseler 2003).

The objective of this paper is to investigate empirical evidence of the impact of Bt cotton varieties on pesticide use and productivity in China several years after technology introduction and determine possible institutional constraints to the full realization of potential benefits. A case study was conducted in Linqing County in Shandong Province, where Bt cotton varieties obtained commercial approval in. In particular, we address the following three questions:

1) What is the status of chemical pesticide use in Bt cotton production?
2) Is Bt cotton an effective and efficient method under the prevailing on-farm and institutional conditions in China?
3) Will Bt cotton lead to a significant and long term reduction in chemical pesticides and therefore generate additional health and environmental benefits?

The remaining text is organized as follows: the next section gives a brief description of the data collection methodology and the analytical procedure. Section 3 shows the pesticide use practices in the study area and provides an assessment of the productivity impact of Bt cotton. In the last section of the paper we draw conclusions and make some suggestions how the methodology for impact assessment of genetically modified crops could be advanced.

2. METHODOLOGY AND DATA

Data collection

One major problem when assessing the impact of Bt cotton on input use and crop productivity in developing countries is the collection of data. As pointed out above, the validity of pesticide use information is crucial when measuring the benefit of Bt cotton, which is mainly attributed to a reduction in pesticide use (see also Falck-Zepeda *et al.* 1999; Pray *et al*. 2001). Measuring pesticide use under the conditions of small-scale farming in developing countries poses a great challenge and requires carefully planned studies with well-designed data collection protocols (Waibel *et al*. 2003). A large array of pesticides is available on Chinese markets and the type of active ingredients and the concentration of the product are often not or only improperly labeled and hence are unknown to the farmer. Also, when pesticide application frequency is high or when mixtures of products are applied, farmers, when surveyed at the end of the season, can hardly remember the pesticide quantities they used in individual sprays. Table 1 gives an overview of the main problems in measuring pesticide inputs and explains how these problems are addressed by data collection with monitoring.

Insert Table 1 here

In this study, we collected data from farmers growing Bt cotton, in five villages in Shandong Province[3]. A total of 150 farm households were interviewed three times during the 2002 cotton season. Data comprised socio-economic parameters, cropping pattern, farmers' perception of pest pressure, and data on production input and yield of cotton. During an orientation phase in the same area (interviews with 60 farm households in 2001) we found that respondents when asked after the crop was harvested were generally not able to remember the amounts and names of pesticides applied in cotton production (Pemsl 2002). Particular care was therefore taken in collecting pesticide use information. To increase data accuracy, each of the 150 farmers recorded all cotton production inputs (labor, irrigation, type and amount of fertilizer and pesticides) for one representative plot over the whole season (April to late October 2002). Recording forms were collected every second week and immediately checked for consistency and completeness together with the farmer.

In order to obtain a measure of the trait "Bt", cotton leaf tissue from each respondent's plot was sampled and analyzed to assess the Bt toxin concentration (ng toxin g^{-1} fresh leaf)[4]. The sample was collected in parallel to the fourth generation of the cotton bollworm (September sample). Terminal leaves from five different points in the plot and for each point for three plants in a row were collected and mixed to obtain the plot sample. Leaves were flash-frozen with liquid nitrogen and kept frozen until laboratory analysis.

Analytical procedure

One possibility to assess the input substitution and productivity effects of Bt varieties as pest control agents is to apply the damage control framework of Lichtenberg and Zilberman (1986). In previous studies (e.g. Huang *et al*. 2002; Qaim and Zilberman 2003) the effect of the Bt trait was captured through a variety dummy using data from the fields of adopters and non-adopters of Bt cotton. The problem with this approach is that such a variety dummy may include also non-pest control effects if other factors cannot be adequately controlled. In our sample we only included farmers that use Bt varieties as in Shandong Province no conventional (non-Bt) seed is available on local markets and therefore adoption must be considered as 100%. Therefore, we include the Bt concentration as a continuous variable in the damage control function.

A problem in estimating production functions, including pest control variables, is that regressors (independent, explanatory variables) are correlated with the production function error term ε (see also Huang *et al.* 2002) because unobserved factors like the climate may results in both high input levels of insecticides and low yields. However, if regressors are correlated with the error term, parameter estimates of ordinary least squares (OLS) procedures are biased and the results inconsistent (Johnston and DiNardo 1997). To overcome the problem of correlation between insecticide use and the error term of the production function, an iterative three stage least square (3SLS) procedure using instrumental variables to estimate the predicted value of insecticide use can be applied (Wooldridge 2002). Thus, the insecticide use function (with the dependent variable 'amount of insecticides') and the production function with the damage control function (dependent variable 'log yield') were estimated simultaneously.

Assuming a Cobb-Douglas type production function with an integrated damage control function the cotton yield y can be described as:

$$Y = a_0 \left[\prod_{i=1}^{n} (x_i^D)^{\beta_i} \right] * G(x^P)^{\gamma} \tag{1}$$

where x_i^D, i=1, 2, …, n, are explanatory variables (independent production inputs like labor, fertilizer and farmer-specific and location-specific factors), β_i are the respective coefficients to be estimated and x^P is a vector of damage control agents within the damage control function G. Following Carrasco-Tauber and Moffitt (1992) who refer to a working paper by Babcock, Lichtenberg and Zilberman, the parameter restriction $\gamma = 1$ was imposed on (1) to facilitate the estimation.

With the introduction of the Bt trait there are two externally supplied damage control agents in cotton production, namely 'insecticides' and 'Bt toxin'[5]. Hence, the specification of the (logistic) damage control function[6] reads as follows:

$$G(x^P) = [1 + \exp(\mu - \sigma_1 x_1^P - \sigma_2 x_2^P - \sigma_3 x_1^P x_2^P)]^{-1} \tag{2}$$

where x_1^P is the Bt-toxin concentration in leaf tissue (ng toxin g^{-1} fresh leaf), x_2^P the amount of chemical insecticides [kg ha^{-1}], and $x_1^P x_2^P$ an interaction term for both control agents. The coefficients σ_1 - σ_3 are to be estimated. For the estimation of the parameters the logarithmic form of the production function is used and an error term ε is added to the equation. The specification of the damage control function ensures that, in principle, the Bt trait and chemical insecticides are substitutes. However, complete substitution is unlikely to occur, since the Bt toxin is only poisonous for lepidopterous pests but does not control other pests e.g. red spider mite *(Tetranychus spp.)* and aphid *(Aphis gossypii)* that are also important in cotton production in North East China.

3. RESULTS

Analysis of pesticide use

The main parameters of cotton production in our sample (Table 2) are in line with other studies (Huang *et al*. 2002). With around four tons the cotton yield level is among the highest globally[7]. Cotton production in the Yellow River Area to a very large extent is still manual work, very labor intensive and mainly relies on family labor. Gross margins excluding labor costs range from about US$1,200 – 1,800 per hectare and returns to labor are in the order of US$4 per person per day. Interestingly, neither yield nor gross margin seems to bear much relation with pesticide use. In fact, farmers in the village with the lowest average number of pesticide applications had the highest average gross margin.

Insert Table 2 here

As commonly the case in cotton the vast majority of pesticides used are insecticides. In the sample of 150 farmers in Shandong Province, on average 96% of pesticides used were insecticides. Based on their active ingredients more than half of the insecticides used by farmers in our case study in 2002 can be assumed to be effective against the cotton bollworm *(Helicoverpa armigera)*, the very pest that Bt varieties intend to control. On average some 30% of all sprays applied by respondents directly target this pest. The range of this share was very high with some farmers not spraying against the bollworm at all and others using as much as 85% of all sprays against this pest. About 60% of the farmers named the cotton bollworm among the three main pests along with red spider mite and aphid. Such decision behavior of farmers who already invested in Bt control through their choice of variety prior to the actual field occurrence of the pest indicates that farmers may not have full trust in the effectiveness of Bt control.

The authors of previous economic studies on Bt cotton (e.g. Pray *et al.* 2001; Qaim 2003) found that Bt varieties not only reduced the amount of chemical pesticides but also the share of highly toxic products and therefore generate additional health benefits. In our study the share of extremely and highly hazardous pesticides (WHO toxicity classification Ia and Ib) was almost 40% on average with some variation across villages (Table 3). It must be noted that in China product adulteration of pesticides is a major problem (e.g. Liu and Qiu 2001). As mentioned above, labeling, more often than not, is improperly done, i.e. no or insufficient information on e.g. active ingredients, concentration and recommended dose is printed on the product container. In the sample, 15% of products could not be identified and are therefore not attributable to a toxicity class.

Insert Table 3 here,

We also checked for evidence of negative human health effects from pesticides in the five villages during the reporting season. We found that most of the poisoning cases were minor health hazards, such as skin irritations after pesticide spraying (Table 4). These were generally not treated beyond washing and the affected person having to rest after spraying. Nevertheless, 13 out of 150 farmers experienced medium or severe[8] poisoning in the 2002 season while or after applying pesticides to Bt cotton. This is a high incidence of negative human health effects of pesticides of farmers using Bt cotton varieties.

Insert Table 4 here

The prevailing high level of insecticide use despite Bt cotton adoption raises some questions regarding the effectiveness of both types of damage control agents, chemical pesticides and Bt varieties. Hence, we first examined the possibility of resistance of bollworm to the Bt toxin. For this purpose, bollworm caterpillars (2nd or 3rd instar larvae) were collected from the plots where input data collection took place and were analyzed for resistance to Bt toxin[9]. The bioassay found that compared to a control strain reared under laboratory conditions, bollworm larvae collected at the study site in 2002 did not show increased resistance against Bt toxins. Therefore, the application of high amounts of chemical insecticides cannot be attributed to pest resistance against the Bt toxin.

A second factor that could help to explain the continued high use of insecticides and the seemingly small substitution effect of Bt for insecticides is the situation in the local seed markets. A vast number of different Bt varieties are available on local markets, with striking differences in price. The price for the Monsanto Bt-cotton variety 33B is around US$10 per kilogram, but as depicted in Figure 2, most farmers actually spent considerably less. Cotton seed is available for less than US$2 per kg and shops[11] sell different qualities even for the Monsanto varieties indicating that counterfeit products exist. Also, before Bt cotton introduction, it was common practice to select seed from the field and keep them for sowing in the next season. As shown in Figure 2, most farmers still continue this practice when using Bt varieties. Own seed is cheaper but might show lower control effectiveness and hence the choice of seeds may influence the use of chemical pesticides.

Insert Figure 2 here

To investigate the presumption that the seed price is related to the control effectiveness, we grouped the sample by seed price. From the analysis of cotton leaf tissue huge variation in the Bt toxin concentration was revealed. Comparing all farmers that used seeds saved from their previous production and those farmers who paid US$2.4 or less per kg of seed with those paying more shows a significant difference in the average Bt toxin concentration (Table 5). This means that when farmers use own or cheap Bt seed the plant tissue is more likely to contain lower toxin levels and hence bollworm control effectiveness could be impaired.

Although higher probability of high toxin concentration would suggest higher control effectiveness, it was found that farmers, who pay more for their seed, also spend more money on insecticides and other inputs (Table 5). The mean values for the amount and number of insecticide applications are all significantly higher for farmers using high priced seed while yield difference is insignificant.

Insert Table 5 here

Potential reasons why farmers do not substitute Bt toxin for chemical insecticides can be multifarious, including continued promotion of chemical pesticides by village leaders or extension agents, fear of bollworm outbreaks, perceived unsatisfactory control by Bt varieties and farmers' lack of ability to assess the control effectiveness of Bt varieties. Although in theory, the effect of Bt toxin on pests is linearly additive and even at low concentration ought to have an impact e.g. by slowing pest development (Adamcyzk *et al.* 2001) this is unlikely to be the base of farmers' decision making. Rather, if they observe that larvae continue feeding on the plant, farmers may consider the toxin as not effective and apply additional insecticides.

We used the results from our cotton growth experiment[10] as standard and found that close to 60% of the leaf samples collected in farmers' fields had toxin concentrations below this standard (Figure 3). There is a high variation in toxin concentration regardless of the seed price but the probability that a farmer has planted *sub-standard* Bt cotton is higher if own seed or lower priced seed were used. However, low toxin levels were also found for more expensive seed, hence farmers cannot be sure about the control effectiveness of Bt varieties.

Insert Figure 3 here

Moreover, reduced control effectiveness due to low toxin levels is difficult to assess for farmers. Therefore, in their attempt to be on the safe side and avoid yield losses, farmers may continue to rely on chemical insecticides. Antle (1983) has pointed out that in a situation with input uncertainty economically optimal resource allocation is hindered because changes in the (environmental) conditions after input decisions have been taken can render these decisions suboptimal. Hence, a substitution of insecticides, even those explicitly targeting the cotton bollworm with Bt varieties does not seem to be very likely under the conditions prevailing in Shandong Province. The continuation of using high levels of insecticides is an indicator of a high degree of uncertainty about the damage abatement effectiveness of Bt seeds. Such behavior could also be a hint that farmers are unaware of the true pest control properties of Bt varieties and instead may associate the higher seed price with other traits, which in reality Bt varieties do not possess. The next section therefore investigates the effectiveness of damage control agents by applying the damage control function methodology.

Production function estimation

The coefficients of the insecticide use function (Table 6) show the expected signs. The number of continuous years of planting cotton on the plot (crop rotation) and high intensity of production (indicated by high labor input; these figures do not include time spent for spraying pesticides) increase the insecticide use while experience and higher price of insecticides (that might be correlated with better quality) negatively influence the amount of applied insecticides. Farmers also used more insecticides if tree cotton (a very tall, bushy) variety was planted. As shown in the descriptive analysis above, insecticide use is higher in the plots were we measured high Bt toxin concentrations. Since insecticide use differed among villages (Table 2), we included a location dummy for the villages. Yield differences between villages might also be attributed to e.g. different soil, climate or infrastructure conditions (e.g. access to wells for irrigation) as well as distinct policies of the village leader or agronomic practices. Following the findings of Huang *et al*. (2002), an important factor might also be a varying extent of pesticide promotion. Farmers generally consult the owner of the pesticide shop as well as extension staff when they observe pests in the field and tend to follow the advice obtained.

Insert Table 6 here

The parameter results of the production/damage control function are in line with production theory i.e. expenditures for inputs other than pest control have a significant positive effect on yield while lack of crop rotation and higher experience (older farmers) tends to decrease yields. The most remarkable result however is that neither the coefficient for insecticides nor for Bt toxin concentration was statistically significant. Considering the high variability in input quality and the generally low variation in pesticide use at generally high levels these results are plausible although they contradict some other studies who found significant effects of the Bt dummy and the applied pesticide quantity on cotton yield (e.g. Huang *et al*. 2002; Qaim and Zilberman 2003).

4. CONCLUSIONS

The results of this case study suggest that the economic benefits of Bt cotton in developing countries could be more limited than assumed in several previous papers (e.g. Pray *et al*. 2001; Pray *et al*. 2002; Huang *et al.* 2003; Thirtle *et al*. 2003; Qaim 2003, Qaim and Zilberman 2003). Most importantly the benefits of this technology depend on the institutional conditions. Lack of standards and unreliable quality of Bt seeds and pesticides limit the potential benefits of all input-based technologies. In addition our results underline the problem of collecting and using pesticide data from small-scale farmers in developing countries as a base for estimating pesticide reduction benefits from Bt crops. It also needs to be stressed that Bt cotton is nothing but a new pest control option for some lepidopterous pests. Therefore its economics crucially depend on the control effectiveness of Bt, i.e. the quality of seeds, the appropriateness of farmers complementary control methods and of course, the severity of bollworm pest pressure. Given the imperfections in the markets for agricultural inputs and the sometimes dysfunctional agricultural extension system in China the effect of Bt crops to reduce the use of toxic chemicals in a sustainable way and therefore realize the potential economic, health and environmental benefits may be lower than suggested by previous studies. Unless the institutional problems are solved the technology may fail to live up to its potential. These are also the simple lessons learned from the economics of pesticides (Zadoks and Waibel 2000). These lessons should not be ignored when drawing conclusions about the prospects of Bt crops to contribute to agricultural productivity growth.

We also see some problems with the damage control function methodology that has been used to assess the productivity effects of Bt crops when applied to the conditions of developing countries. For example, even though the parameter estimates of the production function are in line with production theory the inclusion of pest control variables in this framework remains problematic under the conditions of input uncertainty. Under such conditions, quantity or value of pest control inputs may not sufficiently well describe the biological processes underlying the input output relationship. In conclusion, our research suggests that the discussion on the prospects of Bt cotton and other GM crops in developing countries could benefit from more and better trans-disciplinary communication as regards the assumptions for economic models but also for the interpretation of results. To realize the potential of pest resistant transgenic varieties these should be treated as a component of integrated crop and pest management and not as single solutions. Also, the institutional environment is an important determinant of the resulting benefits of technology introduction. As pointed out by de Janvry et al. (2005), it is a major precondition and challenge for the effective implementation of agricultural biotechnology in developing countries to put in place the necessary public and private institutions. The introduction of such technologies without enabling institutions that assure proper use of the technologies can limit the benefits considerably. The survey and experimental findings presented in this thesis indicate that the implementation of Bt-cotton in China was carried out without the necessary supportive institutions and a stepwise evaluation. To the contrary, the technology was introduced very rapidly without prior implementation and/or enforcement of a set of clear rules and standards.

Endnotes

1 The term biotechnology in this paper refers to the genetic engineering of plants where genes of other plants of animal species are inserted into agricultural crops to obtain transgenic plants with altered traits.

2 As figure for total global agricultural land the 5,020 million hectare stated for 2002 in the FAOSTAT database were used.

3 All five villages are located in Linqing County and village names can be obtained from the authors.

4 Testing was conducted by Dr. Zhang Yongjun, CAAS (Chinese Academy of Agricultural Sciences, Beijing).

5 A range of cultural practices can also be considered as damage control factors but due to the dominance of chemical insecticides and Bt toxin these factors are ignored in the analysis.

6 Other functional forms (exponential and Weibull) of the damage control function were applied (see Pemsl et al. 2003), and did yield similar results.

7 Yield figures are seed cotton (lint with seed). Farmers sell produce as seed cotton without ginning. The weight ratio of seed to lint in seed cotton is about 2:1.

8 Grouping of poisoning into slight (symptoms like skin irritation), medium (symptoms like vomiting and dizziness) and severe (where the farmer needed medical treatment in a hospital and said he nearly died).

9 Prof Wu Kongming at CAAS, Beijing, conducted the bioassay of cotton bollworm.

10 There was at least one small shop in each of the villages that sold agricultural inputs (pesticides, fertilizer and seed) besides a multitude of other items. Farmers also go to the local town to buy in larger shops that are specialised in agricultural inputs.

11 A cotton growth experiment following the recommendations and advice from Prof. A.P. Gutierrez was conducted close to the 5 survey villages. A Bt (33B) and a non-Bt cotton variety (Zhong mian 12) were planted on 108 m^2 plots (three replicates each). During the whole season, plants were mapped weekly and dry weight of stem, leaf, roots and fruits/flowers was determined for 5 sample plants per plot. Toxin concentration was measured at the same time when measurement in farmers' fields took place and yield was measured at the end of the season for each plot.

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Table 1. *Problems in recalling details of pesticide use and monitoring response*

Aspect of pesticide use	Measurement problem	Monitoring response
Dosage	Dosage changes during the season, difficult to remember since mixtures and many applications	Farmers record immediately after each application
Treatment frequency	Long cotton season and high number of pesticide applications	Farmers record immediately after each application
Mixture	Widespread application of mixtures (two or more pesticides)	Farmers record immediately after each application
Names of pesticides	About 500 different products used by the sampled farmers, often very similar names	Farmers can copy names from bottles, interviewer can check bottles
Price of pesticides	Only person who purchases pesticides may know the price; prices change during the season	Farmers record directly, possibility to check with the purchaser

Table 2. *Indicators of Bt cotton production in the study area*

	Village					
	V1	V2	V3	V4	V5	all
Yield, seed cotton [t ha^{-1}]	**4.0**	**3.7**	**4.3**	**3.8**	**3.5**	**3.9**
	(0.88)	*(0.92)*	*(0.68)*	*(0.73)*	*(0.75)*	*(0.84)*
Pesticide applications [Number]	**12.4**	**12.9**	**7.7**	**10.5**	**10.7**	**10.8**
	(3.3)	*(3.4)*	*(1.8)*	*(3.6)*	*(2.5)*	*(3.5)*
Pesticide use [kg ha^{-1}]	**20.5**	**16.9**	**8.4**	**14.3**	**18.9**	**15.8**
	(10.6)	*(8.7)*	*(4.2)*	*(6.2)*	*(8.2)*	*(8.9)*
Average pesticide price [US$ kg^{-1}]	**4.8**	**3.2**	**4.6**	**4.0**	**4.0**	**4.1**
	(1.4)	*(0.6)*	*(1.9)*	*(1.5)*	*(1.0)*	*(1.4)*
Production costs[1] [US$ ha^{-1}]	**411**	**373**	**379**	**400**	**608**	**434**
	(136)	*(104)*	*(102)*	*(114)*	*(207)*	*(162)*
Labor input [person days ha^{-1}]	**432**	**436**	**394**	**425**	**378**	**413**
	(155)	*(165)*	*(107)*	*(122)*	*(112)*	*(134)*
Gross margin [US$ ha^{-1}]	**1626**	**1477**	**1791**	**1640**	**1169**	**1541**
	(381)	*(458)*	*(313)*	*(458)*	*(386)*	*(449)*

[1] Costs for family labor are not included. Wage level for unskilled labor in the area is US$ 1.2 per day.

Note: The sample size is 150, i.e. 30 farmers per villages. Data were collected during May - October 2002. Figures in brackets are standard deviations.

Table 3. *Toxicity of pesticides used in Bt cotton production (WHO classification)*

	Village					
	V1	V2	V3	V4	V5	all
Unidentified pesticides [% of total]	13.8 *(9.8)*	27.2 *(14.1)*	4.2 *(6.7)*	15.7 *(13.1)*	16.5 *(12.9)*	15.5 *(13.6)*
WHO toxicity group [% of identified pesticides]						
Ia	1.1 *(2.2)*	8.6 *(11.1)*	8.9 *(10.8)*	11.2 *(12.3)*	26.2 *(14.6)*	11.2 *(13.7)*
Ib	37.4 *(18.3)*	14.8 *(17.7)*	39.7 *(14.5)*	23.4 *(13.7)*	24.6 *(18.1)*	28.0 *(18.8)*
II	23.0 *(14.9)*	38.3 *(22.4)*	20.1 *(14.3)*	31.3 *(16.2)*	32.4 *(16.5)*	29.0 *(18.1)*
III	36.2 *(13.9)*	29.0 *(17.2)*	26.8 *(16.6)*	30.1 *(16.3)*	8.6 *(8.2)*	26.1 *(17.4)*
U	1.3 *(3.7)*	0.6 *(1.5)*	0.7 *(3.2)*	0.7 *(1.6)*	0.5 *(2.5)*	0.8 *(2.6)*
nl	1.0 *(2.8)*	8.6 *(7.9)*	3.8 *(6.3)*	3.2 *(5.3)*	7.8 *(10.2)*	4.9 *(7.4)*

Standard deviations in parentheses

Ia – extremely hazardous, Ib – highly hazardous, II – moderately hazardous, III – slightly hazardous, U – unlikely to pose an acute hazard in normal use, nl – not listed

Table 4. *Pesticide poisoning in the sample (2002 season) in Bt cotton production*

	Village					
	V1	V2	V3	V4	V5	all
Poisoning cases [% of farmers]	**17**	**23**	**13**	**27**	**43**	**25**
Slight poisoning [% of total]	100	71	100	50	46	65
Medium poisoning [% of total]	0	29	0	50	46	32
Severe poisoning [% of total]	0	0	0	0	8	3
Poisoning symptoms after/while pesticide application in Bt cotton in 2002*						
Skin irritation [% of farmers]	17	17	13	13	17	15
Nausea [% of farmers]	0	0	0	7	7	3
Vomiting [% of farmers]	0	3	0	7	13	5
Headache [% of farmers]	0	0	0	10	7	3
Dizziness [% of farmers]	0	7	0	0	13	4

* Some respondents stated more than one poisoning symptom

Table 5. *Pest control measures of farmers grouped by seed prices*

	Type of seed		
	On-farm propagation	Low price (< US$2.4 kg^{-1})	High price (≥ US$2.4 kg^{-1})
Number observations	N = 85	N = 29	N = 33
Seed price [US$ kg^{-1}]	0.48 [a]	1.99 [b]	5.65 [c]
Toxin concentration[2] [ng g^{-1} fresh leaf]	522 [a]	533 [a]	652 [b]
Yield [t ha^{-1}]	3.88[a]	4.04 [a]	3.70 [a]
Amount pesticides [kg ha^{-1}]	14.7 [a]	14.3 [a]	20.4 [b]
Pesticide applications [number]	10.0 [a]	10.8 [a]	13.0 [b]
Insecticides targeting CBW [kg ha^{-1}]	4.1 [a]	4.4 [a]	7.4 [b]

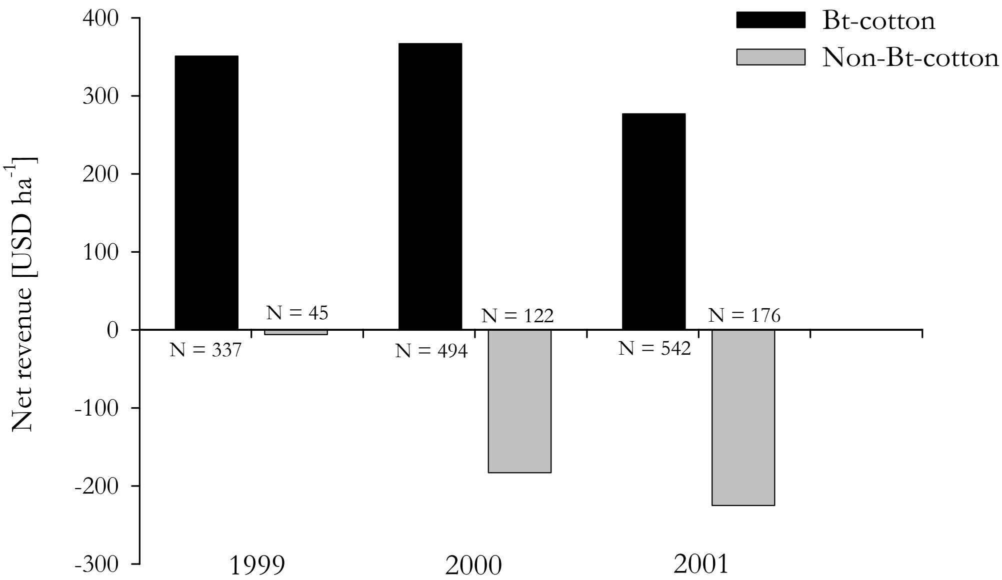
Different letters a, b, c indicate significant difference of means ($\alpha = 0.05$), [2] September samples

Table 6. Simultaneously estimated insecticide use and production function (using 3SLS)

Parameter	Insecticide use function		Production function with logistic damage control function	
	Coefficient	t statistic	Coefficient	t statistic
Constant	5.768	1.53	3.501	0.00
Labor	**0.021**	4.99	0.118	1.66
Experience	**-0.142**	-2.56	0.002	0.08
Crop rotation	**0.252**	1.99	-0.055	-1.65
Input costs	0.001	1.72	**0.130**	2.18
Village 1 (dummy)	**5.210**	2.68	0.077	0.98
Village 2 (dummy)	**5.807**	2.91	**-0.142**	-2.09
Village 3 (dummy)	-2.454	-1.14	0.216	1.65
Village 4 (dummy)	1.119	0.59	0.039	0.60
Insecticide price	**-0.172**	-3.12		
Pest pressure (dummy)	-1.290	-1.09		
Variety (dummy)	**5.063**	2.35		
Bt toxin concentration	**0.005**	2.18		
Damage control function				
Constant µ			3.938	0.00
Insecticide			0.006	0.01
Bt toxin			< -0.001	-0.01
Adjusted R^2			*0.420*	

Note: T statistics larger than 1.98 indicate coefficients that are significantly different from zero, α = 0.05

Figure 1. *Net revenue of Bt and non-Bt cotton production in China*



Source: Based on data from Pray *et al.* (2002)

Figure 2. *Price and source of cotton seed used by the sampled farmers*

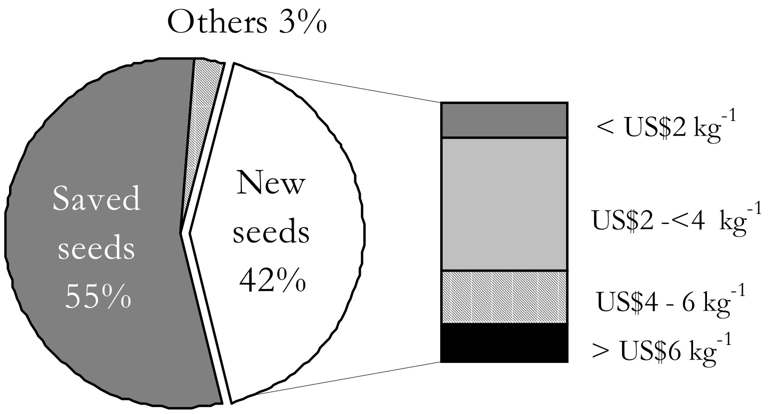


Figure 3. *Cumulative distribution of Bt toxin concentration of monitored plots (September)*