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Challenging the miracle of transgenic crops in China: findings from a case study in cotton using panel data

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Challenging the miracle of transgenic crops in China: findings from a case study in cotton using panel data

Abstract. – Bt cotton has been cultivated in China for the past 10 years. Limitations of previous studies analyzing the impact of this technology are the short time period considered and lack of panel data. In this paper, we present findings from monitoring 150 Bt cotton farmers in 2002 and 2005. Descriptive analysis reveals that pesticide use is increasing while seed price and Bt toxin concentration decreased. The Bt variable was consistently insignificant in a production function with damage control specification model and in a fixed effects model. There is indication that poor standards in pesticides and Bt cotton varieties can cause this result.

Key words - Biotechnology, Bt cotton, productivity analysis, panel data, Asia, China

1. INTRODUCTION

Genetically modified (GM) crop varieties have been cultivated for the last two decades both in developed and developing countries. A large number of papers have been written on the economics of this technology. Many of these studies tried to measure the farm-level impact of herbicide and insect-resistant maize and cotton varieties. To consolidate the evidence, a global review of 47 peer-reviewed economic papers on the farm-level impact of Bt cotton in developing countries was recently conducted by Smale et al. (2006). The authors found that most of the papers focus on China, India and South Africa with economic returns being highly variable over years, farm type, and geographical location. Thus, the study concludes that “*the institutional and marketing arrangements for supplying the technology and marketing the product may be the single most important determinant of Bt impact at the farm-level, even when the trait is shown to be effective*”. The authors also note that the most obvious limitation

to conclude solid evidence of Bt cotton impact is the short time period considered in the studies.

Among the developing countries, China was one of the first to introduce genetically engineered cotton resistant to some insect species, particularly the cotton bollworm, on a large scale⁴. Some economic studies were highly enthusiastic about the merits of the technology for Chinese farmers (see for example Huang et al., 2002a, 2002b, 2002c, 2003, and 2005; Pray et al., 2001, and 2002) while other case studies were more cautious (e.g. Keeley, 2006; Pemsal et al., 2005, and 2007; Fok et al., 2005; Yang et al., 2005a, 2005b). Though a considerable number of studies were conducted to assess the farm-level impact of Bt cotton in China, none of the studies has used panel data. Monitoring the same farms over time, however, is crucial to assess the long-term performance of the technology. This is particularly relevant since questions have been raised with regard to potential resistance built-up of target pests against the Bt toxin (e.g. Carrière et al., 2001; Tabashnik et al., 2003; Wu et al., 2002), though to date none has been detected, higher pest pressure from secondary pests (e.g. Gutierrez et al., 2006; Wang et al., 2006), and maintaining the standard of Bt varieties and other production inputs such as chemical pesticides under developing country conditions due to institutional failure (e.g. Pemsal et al., 2005). All these issues can result in lower benefits of the technology and shorten the service life of this pest control innovation.

In this paper, we analyse a set of panel data collected from 150 farmers in five cotton growing villages in Linqing, Shandong Province, China. The data were collected in a season-long monitoring from the same farmers in 2002 and 2005.

The objectives of this paper are, first, to assess changes in the performance of Bt cotton, the level of input use and the choice of Bt cotton varieties. Second, using a panel data set to measure the productivity effects of chemical pesticides and Bt varieties in 2005 and

⁴ These varieties became known as Bt cotton which contains a gene from the soil bacterium *Bacillus thuringiensis* (Bt). It produces an endotoxin that is lethal for certain pests especially the cotton bollworm.

compare the results with the findings of the analysis based on the 2002 data (see Pemsil et al., 2005, and 2007). Third, to evaluate different methodologies to derive productivity effects of chemical pesticides and Bt cotton varieties using panel data; and last, to discuss the implications of introducing the Bt cotton technology under the current institutional setting present in China.

The analysis in this paper proceeds in three steps: first, descriptive statistics of the farm level data on cotton inputs, and cotton output comparing the 2002 and the 2005 situation are presented. Particular emphasis is given to the aspect of seed quality using the Bt toxin content of the Bt varieties planted by the farmers as indicator. Second, we estimate a production function with integrated damage abatement function (Lichtenberg and Zilberman, 1986) to determine the role of control agents such as chemical pesticides and Bt varieties in productivity. Third, we make use of the panel nature of our data set by estimating a fixed effects model to explain changes in cotton yield and insecticides targeting cotton bollworm (CBW).

2. METHODOLOGY AND DATA

(a) Methodology

The panel data set is first analysed by means of a descriptive analysis using parametric tests. Comparison of the means of variables that describe the performance of cotton production and indicators of the effectiveness of the Bt technology between the two years are carried out. Observed significant differences can be confronted with economic theory and can be taken as indicators of changes in economic and environmental conditions.

As a next step, the impact of insecticide use and Bt toxin on crop productivity is estimated by applying a production function approach. A damage abatement function is incorporated into a traditional Cobb-Douglas type production function to take into account the damage control nature of inputs (Lichtenberg and Zilberman, 1986). A three stage least square

approach is applied where the pesticide price was used as an instrument in the system to estimate predicted values in the quantity of pesticide use.

The specification of the exponential damage control function reads as follows:

$$G(x^P) = 1 - \exp(-\lambda_1 x_1^P - \lambda_2 x_2^P - \lambda_3 x_1^P x_2^P) \quad (1)$$

where x_1^P is the Bt toxin concentration in leaf tissue (ng toxin per g fresh leaf), x_2^P the insecticide use (kg per ha) and $x_1^P x_2^P$ an interaction term for these two control agents. λ_1, λ_2 and λ_3 are the respective parameters to be estimated. Using the panel data set, the model is estimated for the 2002 year data alone and for the pooled data set from both years. The second equation is a combined cross-section, time-variant model with a dummy variable to account for changes over time. Compared with the one-period cross-sectional regression, this model is likely to lead to more solid coefficient estimates because it rests on a larger data set. Thus model estimates for the pooled data set allow us to validate the 2002 results.

One weakness of models that are based on pooled cross-section data is that they solely rely on a farmer-to-farmer comparison. Consequently, there can be unobserved heterogeneity, i.e. variables are omitted, which might be important in explaining variation of the output variable like for example differences in farmers' management ability or in land quality.

To overcome such difficulties, we apply a fixed effects model making use of the panel structure of the data. Compared to the pooled cross-section damage abatement model, the advantage of a fixed effects model is that it uses individual changes over time rather than comparisons between farmers. Hence, estimation biases e.g. due to unobservable factors can be avoided. Generally, the advantage of such a model is that we eliminate the unobserved time-constant unobserved heterogeneity c_i (i denotes individuals). To derive the fixed effects model we start with an error components model, which can be written as:

$$Y_{it} = \beta x_{it} + c_i + u_{it}, t = 1, 2 \quad (2)$$

where x_{it} is a vector of changes in natural resource management measures (i.e. intercropping and rotation), changes in damage control inputs (i.e. Bt toxin, insecticides targeting cotton bollworm, insecticides targeting other pests, and herbicides), and changes in

other production inputs (i.e. labor, material costs), changes in pest pressure as perceived by the farmers and other environmental changes captured in a year dummy.

This model delineates the total estimation error into two components: a) unobserved heterogeneity c_i , which can be assumed constant over time (t), and b) u_{it} as the time varying error, which can change over time and across individuals. For example, changes in land quality due to environmental factors such as wind or water can affect individual farmers differently over time. The fixed effects panel model can then be specified by averaging the observed values from both years for each individual farmer:

$$\bar{Y}_i = \bar{x}_i\beta + c_i + \bar{u}_i. \quad (3)$$

By subtracting the two equations (2) and (3) we result:

$$Y_{it} - \bar{Y}_i = (x_{it} - \bar{x}_i)\beta + (u_{it} - \bar{u}_i). \quad (4)$$

A dummy variable to capture the effect of time was included in the model in order to control for systematic changes that may occur in the survey years, at the study site. Three applications of the fixed effects model can be estimated: (i) with the changes in yield as dependent variable, (ii) with the changes in use of insecticides targeting cotton bollworm (CBW) as dependent variable and (iii) with the changes in use of insecticides targeting other pests as dependent variable.

In summary, the two models, namely a production function with damage control function, and a fixed effect model enable us to test the hypotheses that (a) damage control inputs are important factors influencing productivity and that (b) CBW can be effectively controlled by Bt cotton varieties. The two models rest on different assumptions and thus yield complementary results. The first model allows capturing the nature of damage control inputs in production functions and in addition takes account of possible endogeneity by using an instrumental variable, i.e. the pesticide price. Model two, the fixed effects model, makes use of the panel structure of the data. In principle, this latter model is capable of

avoiding the problems arising from omitted covariates thus overcoming some of the weaknesses of the first model. Comparing the marginal effects of the relevant input parameters across the models in addition to a descriptive statistical analysis can shed more light on the impact of the Bt technology as well as the problems encountered with its introduction under small farmer conditions in China.

(b) Data collection

The data used in this study, were collected from farmers growing Bt cotton, in five villages in Linqing County located in the west of Shandong Province, China. The area is a major cotton producing region in the Yellow River Plain and Bt cotton varieties were first approved in 1997. From around the 2000 or 2001 season onwards, all farmers were growing Bt cotton varieties and non-Bt cotton seed was not even available anymore in the market (Pray et al., 2002; Pemsil, 2006). The five villages were chosen based on their proximity to major markets and roads, as well as the share of cotton in the production system. Within each of the villages, 30 cotton-growing farmers were selected who were willing to participate in the monitoring and in a way that the sample is representative for the community as a whole. Farm households were interviewed three times during the 2002 cotton season and all cotton inputs and outputs were monitored using recording forms. The same procedure of data collection was applied for the same set of farmers in 2005. However, seven observations had to be dropped from the analysis because of missing values in some of the variables, resulting in a final sample size of $N = 143$ in each of the two years.

Data comprises socio-economic parameters, cropping pattern, farmers' perception of pest pressure, and information on production input and yield of cotton. Particular emphasis was given to collecting pesticide use data. Farmers recorded all cotton production inputs (labour, irrigation, type and amount of fertilizer and pesticide products) for one representative plot over the whole season in a recording form in both reporting periods. The forms were

collected, checked and completed together with the farmers in bi-weekly intervals. The monitoring also included expenditures for inputs, timing of all farming activities and detailed information of each pesticide product including pesticide mixtures. The Bt cotton varieties used by the farmers were sampled and the leaf tissue analyzed to assess the Bt toxin concentration (ng toxin g⁻¹ fresh leaf). More details of the data collection procedure have been reported elsewhere (Pemsl et al., 2005).

3. RESULTS

(a) Descriptive analysis

The first step in the analysis is to compare the performance of cotton production in the two observation periods. Such comparison would demonstrate adjustment of farmers' management practices to the effects of Bt cotton and it would indicate whether the technology is likely to increase profitability of cotton production. In Table 1, selected parameters of the sample farmers and Bt cotton production are presented.

Insert Table 1 around here

There are several interesting observations when comparing the 2002 and the 2005 crop year. First, farmers significantly decreased the area planted to cotton. This may be largely due to lower cotton prices until early 2005. However, cotton prices had increased by about 40 % at the time the 2005 crop was harvested. Therefore, gross margins were higher in 2005 as compared to 2002 in spite of over 30 % lower cotton yields.

On the input side, the material costs have significantly increased from 2002 to 2005 mainly because of higher costs for fertilizer, while there was no change in labour and seed costs. The most striking difference is the increase in pesticide use both in terms of quantity and number of applications. While the latter showed a significant increase of over 30 %, the difference in the quantity of pesticides was less but is still significant. In both years, the major shares of pesticides are insecticides, comprising some 96 % of total pesticides applied. As

shown in Table 1, insecticide use against the lygus bug, a pest that was not common before, has increased by a factor of 20. This supports observations made in other papers that the use of Bt cotton may induce the augmentation of secondary pests (Gutierrez et al., 2006; Hu et al., 2006; Wang et al., 2006). Surprisingly, pesticide use against CBW has increased, too, even though all farmers are using Bt cotton varieties. This points to some problems with the technology under the conditions prevailing in Linqing County.

Another proposed benefit of introducing Bt varieties is a reduction in human health costs because of fewer pesticide poisoning cases due to the application of fewer and less poisonous pesticides (Pray et al., 2001). One indicator for human health effects is the toxicity of pesticide products applied. As shown in Table 2, the relative share of extremely hazardous pesticides (WHO classification Ia) has slightly increased. Even though the share of applied Ib class pesticides decreased, the absolute amount of pesticides classified as extremely and highly hazardous (Ia and Ib) has remained almost constant considering the larger amounts of pesticides applied. In 2005, the majority of pesticides used are found in class II but the proportion in class III has decreased. However, almost 25 % of the applied products could not be identified as compared to only 15.5 % in 2002, indicating a major and growing problem with the regulatory system of pesticides in China. No information is available about the toxicity of the unidentified pesticides. So overall, it is hard to conclude any improvement in the risk of pesticide hazards from this in-depth case study.

Insert Table 2 about here

To further explore possible reasons for the increase in pesticide use it will be useful to look at farmers' choice for selecting cotton varieties. Such indicators include: (i) the rate of seed re-use, (ii) the seed price, and (iii) the variety planted by the farmer.

As shown in Figure 1, farmers bought significantly more new seeds in 2005 than in 2002 and tended to rely less on seeds saved from the previous season. One possible explanation for this trend is that while seed costs per hectare have remained constant

(Table 1), the average price of Bt cotton seed has dropped significantly in 2005. The average price per kg of Bt cotton seed in the sample was US\$4.1 (standard deviation 2.9) in 2002, compared to only US\$2.1 (0.8) per kg in 2005. Figure 1 also highlights, that the majority of farmers paid less than US\$2 per kg in 2005, while in 2002 this was only the case for very few farmers who purchased Bt cotton seed. If Bt seed can be purchased at such low price, the labour intensive procedure of selecting, harvesting, and cleaning seeds for saving them for the next season seems no longer worthwhile. The price drop further indicates that the technology fee has disappeared with the number of Bt varieties rising in the market.

Insert Figure 1 around here

The expansion of the Bt cotton seed market is reflected in the diversity of varieties used by the farmers at the study site. While in 2002 the majority of the farmers (combined 63 %) used either of the two Monsanto varieties 33B or 99B, the latter variety has been largely replaced by domestically bred seeds in 2005 (Table 3). In 2005, three varieties, namely 33B and Lu mian yan 19 and 22, the two latter produced by the Shandong Cotton Research Centre, dominated the Bt cotton seed market in the five survey villages¹. All Bt varieties planted in the survey years 2002 and 2005 are of non-hybrid (conventional) type. We have shown before, that seed prices have dropped significantly between the two time periods. It is especially remarkable, that the price premium for the two Monsanto varieties has disappeared. Unlike in 2002, prices of the Monsanto Bt cotton varieties were no longer significantly different from local varieties by the year 2005. Economic theory suggests that the price of a good is determined by its marginal product, which in the case of seeds is influenced by the different traits of the variety. For Bt the effectiveness of the toxin is an indicator of its quality. To test for the quality of different Bt varieties, laboratory tests of Bt cotton leaf tissue were conducted to quantify the Bt toxin concentration². Comparing the Bt toxin concentration within Bt cotton varieties reveals a highly significant decrease for the two Monsanto varieties (33B and 99B) as well as the unspecified samples. None of the local Bt

cotton varieties, which were sold in 2002, were purchased by the farmers in 2005 any longer. Instead, these varieties were replaced by new ones that came into the market. Thus, data was only available from either one of the years due to very short product life cycles, and no comparison could be made across years. The analysis of the toxin content, however, reveals that these new varieties planted in 2005 on average have a lower toxin concentration than the earlier varieties cultivated in 2002. Also, toxin concentration varies highly among varieties and within the same variety as evident from large standard deviations (Table 3).

Insert Table 3 around here

In Figure 2, $N = 143$ observations are considered for 2002 and 2005, respectively, and Bt toxin concentration is plotted against the cumulative percentage of farmers to display the distribution of toxin concentration for each of the years. The 2002 curve dominates the 2005 curve according to the criteria of first degree stochastic dominance (FSD), indicating a significant difference of means between the two groups. Average concentration (each 50 % of farmers have lower and higher concentrations) has dropped from close to 500 ng per g of fresh leaf in 2002, to only 200 ng per g of fresh leaf in 2005. The strong decrease in average Bt toxin concentrations between 2002 and 2005 may be one reason for the rising levels of pesticide sprays against the cotton bollworm.

Insert Figure 2 around here

Interestingly, variation in toxin concentration across the different varieties seems uncorrelated to their price. For example, for both Monsanto varieties, differences in seed prices can also be observed within the same year. At the same time both the average Bt toxin concentration and the average price of the Monsanto varieties decreased significantly between 2002 and 2005. This points to the possibility that counterfeit products have entered the market as it is unlikely that Monsanto would have intentionally decreased the toxin concentration of their seed or lowered their quality control standards. Since differences in prices, however, do

not seem to reflect differences in seed quality, farmers are faced with input uncertainty. This means that even for relatively high priced varieties, the toxin concentration can turn out low (see Table 3). Hence, farmers may act risk averse and increase the level of pesticide use beyond the economic optimum to insure against pest damage if Bt cotton control fails. Overall, the descriptive analysis has highlighted two major issues which will be tested by econometric analysis. The first is the effectiveness of Bt varieties to control CBW given the conditions in the study area, and the second is the contribution of Bt cotton to further reduce insecticide use.

(b) Production function estimation with damage abatement

The production function with damage abatement model was used to assess the productivity effects of the two damage control agents. Table 4 shows the comparison of the results of the damage function equation for the 2002 and the pooled data set of both years. In the 2002 equation, only those cases were included that had matching pairs in the second year. Hence, results are not exactly identical with those published in earlier papers based on the 2002 data only. However, results are consistent as only seven cases had to be dropped. The coefficients of the insecticide use and of the production function are in accordance with production theory. Farmer's pesticide use is affected by insecticide price and the level of productivity. However, the coefficients for the damage control factors are insignificant. This may be explained by the generally low pest pressure observed in both years where pest control measures only have an insurance function.

Insert Table 4 around here

Using the pooled data set for both years, has improved the statistical quality of the equation system. The number of significant variables in the model has increased. Also, the two models are consistent in the direction of coefficients. For example the village dummies that account for differences in unobservable factors (extension service, pesticide and seed

marketing, village leadership, micro-climate and soil conditions etc.) are similar. The introduced year dummy is highly significant in explaining insecticide use (positive effect) and yield (negative effect) highlighting the importance of other external factors such as climate. At a first glance it seems inconsistent that the direction of the year dummy is positive in the insecticide use function while it is negative in the yield function. The results from the pooled data show that farmers behave consistent by increasing insecticide use in the event of higher pest pressure. However, the non-significance of the pest pressure dummy in the yield function suggests that all together pests were not a major constraint to production in either year. In addition, factors not included in the model have influenced the results, e.g. cotton prices have reportedly increased prior to harvest of the 2005 season which is likely to have an influence on farmer's decision-making for input use. This effect is also captured in the "year- dummy".

The most important result however, are that the damage control variables (i.e. quantity of pesticides, the Bt toxin variable and their interaction term) are not significant in the pooled sample. Hence the analysis of the pooled sample confirms the 2002 results. While in principle such results contradict production theory they are consistent with the concept of damage functions which implicitly reflect the fact that pest control agents do not have a direct yield increasing effect but are dependent on pest pressure. Another possible explanation is technical inefficiency in the application of damage control agents, which has been shown from a semi-parametric estimation procedure using the 2002 data (Kuosmanen et al., 2006).

(c) Fixed Effects Model

In order to investigate the effects of the two damage control inputs over time, a fixed effects model was estimated. Results of the estimation with the deviation of yield from the two-year average (linear specification) are reported in Table 5. The main hypotheses to test are that (a) factors under the control of farmers are significant in explaining the difference and that (b) damage control inputs are among those factors. As shown by the highly significant year

dummy some of the yield difference is due to environmental factors, most of which are beyond the control of farmers. The difference in observed pest pressure as perceived by farmers - which was slightly higher in 2005 - had a negative effect on the difference in yields. At the same time, the difference in insecticide use against other pests had a significant positive effect. Most importantly, however, the Bt variable and insecticides targeting CBW were not significant thus confirming the results of the damage function procedure. However, the variable insecticide use against other pests was significant indicating some change in the pest populations.

To test the robustness of our findings, we did also run the model with significant variables only and with robust standard errors and found that the coefficients are consistent.

Insert Table 5 around here

We also used the fixed effects model to explain the change in the amount of pesticides farmers use against the cotton bollworm. Based on other studies in China, Bt varieties can be expected to reduce the need to spray insecticides against this pest and we can assume that such effect would increase over time since no evidence of resistance against Bt under field conditions has been found so far (Wu et al., 2002).

Results presented in Table 6 question this claim. Farmers who grow Bt varieties with higher Bt toxin concentrations show no tendency to reduce their sprays against the CBW. However, the equation shows that other variables can explain the change in pesticide use including labour, non chemical control measures (intercropping), the price of insecticide and other environmental factors as captured in the year dummy. The variable yield differences (Table 6) does not contribute to the explanation of the change in pesticide use. The coefficient for insecticide prices has the expected sign. Note that insecticide prices as well as cotton prices had increased in 2005. Individual farm gate prices for cotton were not collected in 2005, so it was not possible to use relative prices. It is also interesting that increased spraying against other pests, which were claimed having occurred after the introduction of Bt varieties,

does not reduce the tendency to spray against the CBW. This indicates that farmers after adopting Bt could be worse off as they are faced with the same level of CBW while being faced with higher levels of other pests.

Insert Table 6 around here

In summary, we find that the models confirm the observations from the descriptive analysis. The econometric analysis yields insignificant effects of Bt concentration on productivity and it is also unlikely that the use of Bt varieties will lead to significant reductions in pesticide use (Bt variable not significant in the insecticide use function).

(e) Model Comparison

The econometric models applied to the same data set differ in their theoretical foundation but they are capable to tackle the same question, namely, what is the role of Bt cotton in minimizing crop losses from CBW and in reducing the amount and frequency of insecticides. The damage control model facilitates the estimation of the marginal productivity of pesticides and of Bt. Unlike in the classic ‘with and without’ comparison we are using a quantitative measure of Bt included as a continuous variable in the model. Given the high variation in Bt quality and the growing number of varieties, a dummy variable for Bt does no longer sufficiently reflect reality. The first model was effective in confirming the result we found in our earlier analysis using the same model but limited to the 2002 data. The pooled model has shown non-significance of both the coefficients for the pesticide and Bt variables. This second estimation is not a result of a small sample size and while it is not a proof of insignificance, it is likely to be a demonstration of lack of causality. Given the randomness of both pesticide and Bt quality, rational input use becomes an impossibility for the farmer. The fixed effects model is in principle capable to overcome some of the statistical weakness of the first model. Making use of the panel structure of the data, farmer-specific differences can be eliminated. In addition, the fixed effects model captures changes over time that are expected to occur over

continuous growing of Bt varieties. Hence, the significance of the Bt variable is an indicator for the role of the technology in the process of change.

Looking at this parameter, the two models are consistent in the sense that neither Bt toxin concentration nor insecticides are significant in determining yield or in explaining changes in yields. One possible explanation for this result is that there are simply other factors, which were more important during the period of observation. Of course that does not mean that this is always the case as pest populations may change over time. However, given the very low and declining Bt toxin concentration there is a possibility that a ‘minimum efficacy level’ of this control agent exists. A similar assessment can be given for insecticides where the level of uncertainty is rising with a growing share of pesticides that cannot be identified. Moreover, additional factors related to the skills of the farmer such as the match of pesticide product and pest, and the timing and way of application considerably determine the control effect of pesticides. As found in the detailed monitoring of pesticide use, it is common practice in the area to mix different pesticides in one application. The combination of certain chemicals may render all or part of the mixture ineffective.

4. CONCLUSIONS

The development and introduction of transgenic Bt cotton varieties in China seemed to promise an easy way out of the pesticide dilemma, that had existed in cotton production for a long time. A number of impact studies (Huang et al. 2002a, b, c; Huang et al. 2005; Pray et al. 2001 and 2002) supported this expectation. However, in the light of the results of this in-depth case study, the findings of previous ex-post impact studies should be reconsidered. This study underlines clearly that the economic impact of Bt is dependent on a number of factors that can vary over space and time.

To be realistic about the contribution of Bt varieties to increases in productivity it is important to recognize the nature of the technology. Bt cotton varieties are a pest control

measure effective only against a certain range of pests. They can have a yield effect through better bollworm control and a pesticide reduction effect if farmers who use Bt varieties substitute pesticides they would otherwise have sprayed against the bollworm. Both effects are conditional.

First, the yield effect depends on the probability of cotton bollworm infestation and the effectiveness of the toxin. In our case study light trap catches (data from the Agricultural Extension Bureau in Linqing County) and information on farmer perception (see Table 1) show that in both observation years, i.e. 2002 and 2005, bollworm infestation was only slight to moderate. From the analysis of leaf samples we found a low and declining toxin concentration in all Bt varieties which questions their effectiveness under field conditions. These observations are confirmed in our model results. Neither of the two damage control agents had a significant effect on cotton productivity. It must also be taken into account that the effects of damage control inputs on yield loss reduction cannot be demonstrated if the measurements of the explanatory variable are subject to uncertainty. Then a major assumption of econometric models is violated as the observed variation of independent variables is correlated with the error term and regression coefficients are insignificant or become biased. The message that emerges from such results is that the true effects of damage control agents are unobservable under conditions, which can be found quite often in developing countries. This is particularly the case when the amount of insecticide is used as a variable and where quantity is based on recall information instead of field measurements. For the Bt variable, the actual measurements that were taken from farmers' fields indicate that in many cases the toxin levels may be below the minimum efficacy level resulting in the same statistical problems as for the pesticide variable. The pooled sample of 286 cases further eliminates the possibility that the insignificance of the coefficients is merely the result of a low sample size. The fact that other studies found significant differences of the Bt dummy variable is no proof for causality. This could also be a direct result of the choice of the counterfactual. For

example, in the study of Pray et al. (2002); average net returns of non Bt cotton farmers was negative in all three years of observation and non Bt cotton farmers used an average of 60 kg of pesticides, which is an exceptionally high amount.

The second potential impact of Bt is pesticide reduction. Farmers could partially substitute those pesticides they would otherwise have sprayed against CBW by investing more in seeds, i.e. buying higher quality insect-resistant seed. Whether and to what extent they do this depends on relative prices and on their perception of the technical rate of substitution. If pesticide prices increase and prices for Bt seeds decline then one would expect significant pesticide reduction. The risk premium for bollworm control investment in Bt seed (at a point in time where uncertainty about CBW infestation is highest) declines relative to a pesticide-based strategy. In our case study, exactly those price effects did occur but no pesticide substitution took place. To the contrary, farmers increased their pesticide use against the CBW in 2005 as compared to 2002. One explanation is that the rising cotton prices during the season lowered the economic threshold for pesticide applications and gave incentives for additional sprays. Pesticides are a more flexible response to CBW pest pressure than Bt varieties.

It is nevertheless possible that substitution of pesticides by Bt may have taken place in the past. However, such substitution does no longer take place five to seven years after first adoption. Our fixed effects model suggests that changes in the level of Bt efficacy do not affect changes in pesticide use. However, other factors partially could explain the growth in pesticide use over time. One factor that has been shown empirically to contribute to pesticide reduction is farmer knowledge of integrated pest management practices (e.g. Yang et al. 2005a and 2005b). Hence, adoption of Bt varieties is an insufficient condition for pesticide reduction.

One of the major lessons from this case study is that the impact of Bt cotton in China and perhaps in other developing countries cannot be reliably measured by the classic ‘with

and without' comparison. The impact depends on the conditions under which such studies are carried out. Many cotton ecosystems can be called disturbed (i.e. the abundance of activity level of natural enemies is reduced) as a result of prior pest control interventions. It is therefore not surprising, as demonstrated in past studies in China, that Bt shows good yield effects if measured against natural control or inefficient pest management practices (Pemsl et al., 2008). However, since both, insecticides and Bt varieties can disturb beneficial organisms, simple comparisons between farmers using Bt with those who do not are flawed. Whether Bt varieties will actually reduce excessive use of pesticides, diminish ecosystem disturbance and hence generate additional environmental and health benefits depends on the quality of the technology product and on the environmental conditions. In addition, results from 'with and without' comparisons are further confounded by the emergence of secondary pests under Bt regimes which may result in additional pesticide use. Therefore, to measure the true impact of Bt under on-farm conditions the baseline data prior to Bt introduction would be necessary. However, this is no longer possible given the widespread distribution of a large number of Bt varieties in China. Thus, as pointed out by Pemsl et al. (2005), the analysis of the factors that determine impact is more meaningful than simple 'with and without' comparisons.

Major concerns to be addressed in future studies are (i) the rather liberal breeding policy for Bt varieties in China, (ii) the enforcement of quality standards (Fang et al., 2001) and (iii) intellectual property rights (IPR). It has been argued (Basu and Qaim, 2007) that from a welfare economics point of view zero enforcement and consequently tolerating the existence of "illegal GM markets" can be an optimal strategy because zero IPR enforcement would lower the price of legal Bt seeds. On the other hand, as shown in this case study, the legal GM seed market may actually disappear because agents in the seed distribution system do not have any incentive to maintain it. In Linqing County, a large number of breeder organisations generate an array of products with very little information on their performance and local seed dealers seem to minimize costs by adopting sales strategies that include mixing

of varieties with different degrees of quality. The rapid introduction of a large number of Bt varieties has lowered the Bt cotton seed price but the technology has become subject to the same kind of market imperfections that have long been observed and reported for chemical pesticides in China (Zhang et al., 2003). As shown in a simulation study of different crop protection strategies for cotton, the optimal strategy for farmers is the combination of low quality Bt and pesticides (Pemsl and Waibel, 2007). Thus, while in the initial phase of introduction the Bt technology may have made some contribution to overcome the problem of CBW damage, weak institutions have lowered the benefits.

In conclusion, this case study has elicited some issues with regard to biotechnology in China that point to the need for further in-depth studies. A major challenge is to find incentives that facilitate enforcement of standards for seeds and pesticides. If the current conditions in this respect prevail, the Bt technology could run into similar problems as those that still exist for chemical pesticides forty years after they were introduced in developing country agriculture.

Notes

- 1 Cotton is listed as one of the 5 major crops in China (together with rice, wheat, corn and soybean). Provincial or national registration is required for commercial use of the seeds of major crops. The Examining and Approving Committees under the Ministry of Agriculture or Provincial Departments of Agriculture are responsible for registration. Breeding institutes or companies submit applications for registration and propose areas suitable for cultivation. Regional trials are first conducted to test the productivity, adaptability to regional conditions and stress resistance (5 sites, 3 repeats and at least 2 seasons). Then production trials are carried out to further test the performance under “real” production conditions (5 sites in one ecological zone, the plot area in every site should be between 300 m² to 3000 m²). Based on the results

from those trials, the Examining and Approving committees decide whether to approve the application or not. Varieties with provincial registration can only be released in respective province, but those passing the national registration can be extended to all suitable ecological zones across the country. For transgenic varieties, bio-safety certificate is required prior to registration and the trials can only be conducted in areas designated in the bio-safety certificate. However in practice, it seems that such pre-requirement has not been strictly imposed. For some transgenic varieties, the bio-safety certificate and registration were issued at similar time which shows that bio-safety test and tests for registration were conducted in parallel instead of in sequence. *Source: Ministry of Agriculture (2001). Rule on the examination and approval of varieties of major crops. February 12, 2001 promulgated.*

- 2 Testing of cotton leaf tissues on Bt toxin concentration in both study years was conducted by Prof. Wu Kongming and Dr. Zhang Yongjun, Chinese Academy of Agricultural Sciences (CAAS).

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Table 1: Production indicators for Bt cotton in 2002 and 2005

	2002		2005		Average change in %
	Sample Average	Stand. Dev.	Sample Average	Stand. Dev.	
Landholdings [ha]	0.59	0.21	0.53	0.15	-9.9***
Cotton area [% of total land]	64.4	23.1	41.9	15.9	-35.0***
Cotton yield [t per ha]	4.88	0.82	3.32	0.46	-31.9***
Variety [dummy: 1 = tree cotton]	11	-	0	-	-
Experience [years of cotton]	20.7	10.5	23.7	10.5	14.5
Crop rotation [continuous years of cotton]	5.1	4.3	6.5	3.6	28.5***
Intercropping [area in hectare]	0.2	0.2	0.1	0.1	-46.0***
Pest pressure [dummy: 1 = higher than normal]	52	-	59	-	-
Number of pesticide applications	10.7	3.3	14.2	3.0	32.1***
Pesticides ¹ [kg per ha]	15.6	8.9	18.6	8.5	19.2***
Insecticide price ³ [US\$ per kg]	3.7	1.2	4.4	1.3	20.2***
Insecticides targeting CBW [kg per ha]	4.7	4.4	6.1	5.2	28.5**
Insecticides targeting lygus bug [kg per ha]	0.2	1.0	5.1	3.1	2392.3***
Insecticides targeting other pests [kg per ha]	8.8	5.4	6.5	3.0	-26.4***
Herbicides [kg per ha]	2.1	1.0	2.5	1.2	29.2***
Material costs ² [US\$ per ha]	430	155	503	135	17.2***
Seed costs [US\$ per ha]	41.7	21.9	40.7	21.5	-2.4
Labor costs [US\$ per ha]	499	160	492	79	-1.4
Fertilizer costs [US\$ per ha]	232	133.4	405	129.6	74.5***
Local cotton output price [US\$ per kg]	0.51	0.03	0.74	0.02	45.0***
Gross margin [US\$ per ha]	1565	438	1825	308	16.6***

***, **, and * denote significantly different sample means at $\alpha = 0.01, 0.05, \text{ and } 0.1$, respectively. ¹ Pesticides reported here do not include herbicides. ² Material costs include expenditures for irrigation, fertilizer, mulching, and machinery; but costs for seed and labor (entirely family labor, opportunity costs of US\$1.2 per person day (8 hours) were assumed) were not included in material costs. ³ Insecticide prices have been deflated (2002=100%). N = 143 per year.

Table 2: Average share of unidentified pesticides and toxicity of identified pesticides used in Bt cotton production in Linqing County, 2002 and 2005 (WHO classification)

	2002		2005	
	% of total	Standard Deviation	% of total	Standard Deviation
Unidentified pesticides	15.5	13.6	24.1	15.7
WHO toxicity group	% of identified pesticides	Standard Deviation	% of identified pesticides	Standard Deviation
Ia – Extremely hazardous	11.2	13.7	13.5	17.3
Ib – Highly hazardous	28.0	18.8	19.0	15.9
II – moderately hazardous	29.0	18.1	54.2	21.6
III – slightly hazardous	26.1	17.4	12.4	13.9
U – unlikely to pose an acute hazard in normal use	0.8	2.6	0.9	3.3
nl – not listed	4.9	7.4	/	/

Table 3: Shares of cotton varieties in % of farmers, average price per farmer of purchased seeds and average toxin concentration by varieties

Cotton variety	Shares of cotton varieties (% farmers)		Average price of purchased seeds (US\$/kg)		Average toxin concentration (ng per g fresh leaf)	
	2002	2005	2002	2005	2002	2005
33B	16.1	27.3	3.37 (1.71)	2.05 (1.06) **	490 (105)	257 (100) ***
99B	46.2	9.1	3.13 (1.90)	1.32 (0.00) **	484 (239)	191 (92.6) ***
Lu mian ye 18	16.1	1.4	2.76 (0.96)	1.10 (0.00) **	491 (215)	-
Zhong mian	1.4	-	1.93 (0.00)	-	794 (0)	-
Shu mian/tree cotton	6.3	-	10.12 (0.00)	-	509 (159)	-
Lu mian ye 16	1.4	-	2.95 (0.09)	-	381 (33.4)	-
Lu mian yan 19	-	24.5	-	1.68 (0.05)	-	186 (111)
Lu mian yan 21	-	9.8	-	2.22 (0.04)	-	186 (86.5)
Lu mian yan 22	-	23.8	-	2.48 (0.40)	-	226 (124)
unspecified	11.9	12.6	2.89 (0.46)	1.31 (0.20) ***	606 (196)	229 (67) ***

Note: N = 143 in each year for shares of cotton varieties. N = 58 in 2002 and N = 91 in 2005 for average prices. 2005 prices deflated using price index for agricultural inputs (available from Ministry of Agriculture). Figures in brackets are standard deviations. ** and *** denote statistically significant difference between the two survey year means at 5 % and 1 % level, respectively.

Table 4: Estimated parameters for the 3SLS damage abatement model for 2002 data only (N = 143) and pooled data set for 2002 and 2005 (N = 286)

Parameter	Insecticide use function		Production function with exponential damage control function	
	2002 only	pooled sample	2002 only	pooled sample
Constant	-0.690	0.238	0.115	0.026
Labor ¹	0.031	0.145	0.103**	0.111*
Herbicide	-0.219	-0.126**	0.070*	0.050**
Experience	-0.164*	-0.182***	0.012	0.008
Crop rotation	0.271**	0.171***	-0.047	-0.041***
Material costs ²	–	–	0.103	0.134***
Village 1 (dummy)	-0.159*	-0.110***	0.045*	0.029**
Village 2 (dummy)	-0.209**	-0.179***	0.032	0.023
Village 3 (dummy)	-0.503***	-0.322***	0.066**	0.067***
Village 4 (dummy)	-0.246***	-0.236***	0.031	0.022
Insecticide price	-0.492**	-0.491***	–	–
Pest pressure (dummy)	0.079	0.075***	-0.026	-0.013
Variety (dummy)	0.192*	0.139**	-0.018	-0.021
Cotton yield	3.199**	1.501***	–	–
Bt toxin concentration	0.056	0.036	–	–
2005 year dummy	–	0.415***	–	-0.152***
<i>Damage control function</i>				
Insecticide λ_1	–	–	3.159	0.267
Bt toxin λ_2	–	–	-0.004	0.082
Bt toxin*Insecticide λ_3	–	–	< -0.003	-0.002
<i>Adjusted R²</i>	<i>0.680</i>	<i>0.608</i>	<i>0.174</i>	<i>0.707</i>

Note: ***, **, and * denote coefficients significantly different from zero at $\alpha = 0.01$, $\alpha = 0.05$, and $\alpha = 0.1$, respectively; ¹Without labor used for pesticide application or manual pest control. ²Material costs include expenditures for irrigation, fertilizer, mulching and machinery. Costs for labor (entirely family labor), seed costs (due to possible interdependence of seed quality and toxin concentration) and pesticides were not included.

Table 5: Estimated parameters for the fixed effects model (linear specification) with deviation of cotton yield from two-year mean as dependent variable

Parameter	Coefficient		Standard Error	t-value
Intercept	4.2715	***	0.248	17.95
Labour	< 0.001		< 0.001	1.33
Rotation	0.012		0.014	0.84
Pest pressure	-0.136		0.082	-1.65
Herbicide use	0.107	***	0.036	2.93
Material costs	< 0.001		< 0.001	1.33
Intercropping	0.266		0.312	0.85
Year	-1.576	***	0.104	-15.14
Insecticides targeting CBW	-0.008		0.011	-0.74
Insecticides targeting other pests	0.017	*	0.009	1.94
Bt toxin	< -0.001		< 0.001	-1.26
R ² within			0.844	

Note: N = 286 (143 per year). * indicates statistically significantly different from zero 10% level, ** at 5% level and *** at 1% level. F-test for joint significance: $F(10,133) = 72.13$; $\text{Prob}>F=0.0000$. F-test that all $c_i=0$: $F(142,133) = 2.28$; $\text{Prob}>F = 0.0000$.

Table 6: Estimated parameters for the fixed effects model (linear specification) with deviation of insecticides targeting CBW from two-year mean as dependent variable

Parameter	Coefficient	Standard Error	t-value
Intercept	6.619 **	3.488	1.9
Labor	0.006 **	0.003	2.0
Rotation	-0.084	0.108	-0.78
Pest pressure	0.859	0.631	1.36
Herbicide use	0.423	0.289	1.46
Intercropping	3.990 *	2.387	1.67
Yield	-0.222	0.661	-0.34
Year	2.657 *	1.412	1.88
Insecticide price	-0.922 ***	0.267	-3.45
Insecticides targeting other pests	0.040	0.0690	0.59
Bt toxin	<0.000	0.002	0.16
R ² within		0.2181	

Note: N = 286 (143 per year). * indicates statistically significantly different from zero 10% level, ** at 5% level and *** at 1% level. F-test for joint significance: F(10,133) = 3.71; Prob>F = 0.0002. F-test that all c_i = 0: F(142,133) = 1.85; Prob>F = 0.0002.

Figure 1: Share of saved seeds and price of purchased seeds in 2002 and 2005

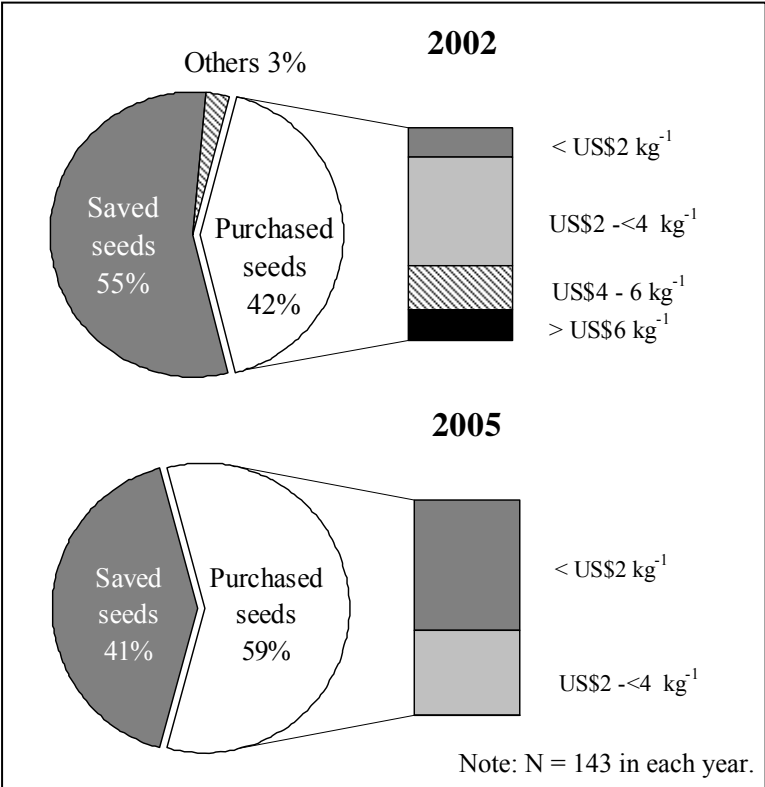
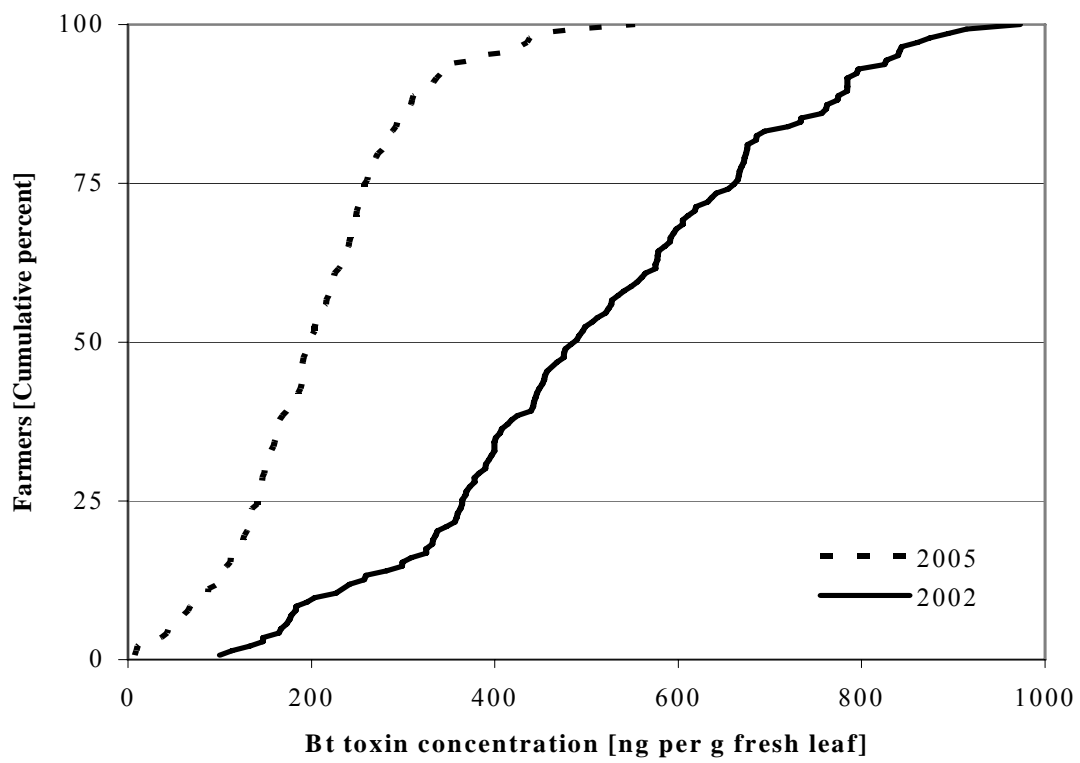


Figure 2: Bt toxin concentration in cotton leaf tissue 2002 and 2005



Note: Leaf tissue samples were taken in August in both survey years. N=143 in each year.