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Small holders, Transgenic Varieties, and Production Efficiency: The Case of Cotton Farmers in China

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Abstract

The overall goal of this study is to measure the effect of the impact that genetically modified cotton varieties have had on the production efficiency of small holders in farming communities in China. We also find that the adoption of Bt cotton varieties leads to a significant decrease in the use of pesticides. Hence, we demonstrate that Bt cotton appears to be an agricultural technology that improves both production efficiency and the environment. In terms of policies, our findings suggest that the government should investigate whether or not they should make additional investments to spread Bt to other cotton regions and to other crops.

Small holders, Transgenic Varieties, and Production Efficiency: The Case of Cotton Farmers in China

Farmers in developing countries, including China, have greatly increased production of food and fiber crops during the past several decades in no small part as a result of increases in the use of modern inputs, especially farm chemicals. Particularly after the spread of modern, semi-dwarf, high-yielding varieties in the 1960s and 1970s, China's producers began using increasingly higher levels of pesticides to offset and avoid damage inflicted by insects and diseases. Although the lack of consistent data makes international comparisons difficult, a recent study by the authors argues that since the mid-1990s China has become the largest pesticide user in the world (Huang et al., 2000c).

While the rising level of pesticide use certainly has helped China raise production, the high, perhaps excessively high, levels of pesticide use may have had a number of adverse consequences. Pesticides may pose a serious danger to the soil and water quality of the agro-ecosystem (Smil, 1993; Rozelle, et al., 1997); human health (Rola and Pingali, 1993; Pingali et al., 1994; Huang et al., 2000b); and food safety (Liu, Cheng, and Wang, 1995). In fact, the negative indirect effects and social costs in some cases may exceed the private cost of purchasing pesticides (Huang et al., 2000b).

Recognizing the negative externalities of excessive pesticide use, China's government has made an effort to regulate pesticide production, marketing, and application since the 1970s. The experience with regulation, however, has shown that when officials only promulgate rules, reductions in the use of pesticides, the elimination of banned toxic ones, or the increase in the adoption of safe application productions do not always follow. In many regions of the country and in the case of many crops, farmers still use high levels of sometimes highly hazardous pesticides (MOA, 1990-1999; Huang et al., 2000b).

As a result, real reductions in the use of pesticides may have to depend on alternative approaches, such as the adoption of new technologies. For example, the spread of host-plant resistant varieties in the past two decades has effectively reduced pesticide use without affecting yields (Widawsky et al., 1998; Pray et al., 2000; Huang et al., 2000a). China's effort to produce and promote host-plant resistant varieties has successfully extended such varieties to almost 100 percent of China's rice, wheat, and maize area.

Despite such success, challenges remain in China's battle against pests. One study provides evidence that the effectiveness of older rice varieties has fallen over time because of the rising resistance of pests (Widawsky, 1996). Interviews with wheat breeders revealed that breeding resistance to certain diseases takes up an increasing part of their breeding effort. In some cases, most notably that of cotton, despite intensive conventional plant breeding efforts, the resistance of pests to the natural defenses of resistant varieties has built up to such an extent that crop damage has risen despite increasingly intensive pesticide spraying campaigns (ERS, 1995).

In response to both the previous successes in traditional plant breeding and the continuing difficulties of mounting resistance, since the late 1980s scientists in China have followed the lead of others in the US and elsewhere and started developing crops that are genetically engineered to be resistant to important pests (Huang et al., 2001). One of the most successful genes to be inserted into plants is one from a bacteria Bacillus thuringiensis (Bt). The Bt gene has been used as a natural pesticide for decades. Currently, China's breeders are developing and testing about 20 genetically modified plants (Huang et al., 2001).

Because of a perceived crises in the cotton sector--due to the ineffectiveness of varieties produced by conventional breeding methods and the rising use of pesticides by farmers--in 1997 Ministry of Agriculture approved the commercial use of cotton varieties that were genetically engineered with a Bt gene to produce the toxin that kills bollworms.

Monsanto in a joint venture with the Hebei provincial seed company introduced an American variety that had been genetically engineered. The Institute of Biotech Research of Chinese Academy of Agricultural Sciences (CAAS) introduced and extended several local cotton varieties that were engineered to include Bt in the same year. The Chinese Cotton Research Institute of CAAS in Henan has also released Bt cotton varieties. Various estimates of Bt cotton area in 2000 ranged from 400,000 to 700,000 hectares. Whatever the estimate, it is clear that cotton producers are among the millions of farmers who are using transgenic varieties.

But despite the unprecedented release and adoption of genetically modified cotton varieties, little is known about the impact they have had on the farm households using them and on the overall agricultural economy in which they are being extended. Has the adoption of Bt varieties of cotton affected the use of pesticides in China? If so, by how much? Once adopted and after accounting for pesticide use, has the adoption of Bt cotton affected yields? If so, by how much? And, more methodologically oriented, how should the impact of Bt cotton on yields be best measured.

To meet the above goal and have a better understanding of the questions raised above, the rest of the paper is organized as follows. In the first section, we describe the data set that we collected in 1999 from a farm household survey. A total of 282 cotton farmers were randomly selected from 10 villages in 5 counties from Hebei and Shangdong. In Section 2, an overview of the pest-related crop yield losses and measures to control the pest problems in China is presented. Section 3 develops an empirical model that will be used to measure the economy of transgenic crops with resistance to pest. The models then are estimated using our data and the results of econometric estimation are presented. Conclusions and policy implications from this study are provided in the final section.

Data

To examine the impact of biotechnology on pesticide use in the cotton sector, we collected our own data set in 1999. Our own data collection was necessary because China's government does not have a program to track the cost of production of transgenic crops. In total, we collected data on the production practices of 282 cotton farmers. Since farmers use Bt and non-Bt varieties, we have information on 382.

The enumeration team put in considerable effort to choose the sample. Since one of our main objectives was to compare the differences in production practices of Bt and non-Bt varieties (and among Bt varieties), we had to carefully select our provinces and counties. In many counties 100 percent of the farmers were growing Bt cotton; in other areas the number of farmers growing Bt cotton was less. The coverage of specific varieties tended to be concentrated in certain areas. We chose Hebei Province because it is the only province in which Monsanto varieties had been approved for commercial use in the survey year. Within Hebei province, we selected Xinji County because that is the only area where the newest CAAS genetically engineered variety was being cultivated. We chose the sample counties in Shandong Province because one of CAAS's most successful Bt cotton varieties, GK-12, was grown there. Since the Bt program started later in Shandong Province, farmers still had significant area in non-Bt cotton varieties. After county selection, we randomly selected the villages and farmers within the villages. The final sample comes from nine villages in five counties in Hebei and Shandong Provinces.

Descriptive statistics illustrate that our sample of farmers are fairly typical of those engaged in cotton production in Hebei and Shandong Provinces (Table 1, columns 1 and 2). Farmers cultivate an average of 0.78 hectares per household, higher than Hebei and Shandong average (0.43 hectares), but nearly the same as the cotton production regions in Hebei and Shandong (0.7 hectares). Cotton area accounts for 0.42 hectares per household, about 39 percent of total sown area in the five counties surveyed in Hebei and Shandong (rows 2 and 3).

Users of Bt and non-Bt cotton also appear to be fairly similar (Table 1, columns 3 to 6). Although cotton area under Bt varieties in the sample region accounts for around 90 percent of total cotton area and more than 90 percent of households in 1999 (bottom row), there are no apparent systematic differences in the type of farmer that is using Bt cotton. T-tests (between columns 3 and 5) demonstrate that there are no statistically significant differences among Bt and non-Bt farms in terms of farm size, cotton area, or the age or education of farm household head. Based on these comparisons, it appears as if there is little problem of selection bias in our sample.

Producing Bt and non-Bt Cotton in China

Yields, prices and the mix of fertilizers used for the Bt and non-Bt varieties are similar (Table 1, rows 6 to 9). On average, the yield of Bt cotton is 5.8 percent higher than non-Bt cotton, but one level is not statistically distinguishable from the other. The prices that farmers get for Bt and non-Bt varieties are virtually the same. The mixes of fertilizers (the ratios of phosphates and potash to total fertilizer use) are also nearly the same.

In other ways, the production technology of Bt and non-Bt vary sharply (Table 1, rows 10 to 15). For example, Bt cotton farmers use more fertilizer. On average Bt cotton farmers apply 407 kilograms per hectare of chemical fertilizer, a level that is nearly 70 kilograms per hectare, or 20 percent more, than that used by non-Bt cotton farmers.

The largest difference between Bt cotton and non-Bt cotton production is in the use of pesticides. Bt cotton farmers apply pesticide only 6.6 times per season compared to nearly 20 times per season by non-Bt cotton farmers. On a per hectare basis, the pesticide use of non-Bt cotton production is more than five times higher than Bt cotton in terms of both quantity and expenditures. Bt cotton farmers spend 261 yuan per season on pesticide for spraying for non-bollworm pests while non-Bt cotton users spend 1465 yuan. Because of the reduction of pesticide application in Bt cotton, Bt cotton farmers reduce their total labor output by 15 percent when compared to non-Bt cotton farmers, including labor saved from pesticide application and pest monitoring in the fields.

Crop Production Loss and Abatement

The frequency of pest outbreaks in the cotton sector has been increasing sharply over time in China, some estimating that the frequency of infestations have doubled over last 10 years (ERS, 1995**;** Huang, et al., 2000c). Increases in the intensity of crop production, longer periods of time when the crops are not monitored due to rising wages, and excessive pesticide use have led to higher pest populations and to higher resistance of pests to the pesticides that once effectively controlled them.

Because of the high incidence of pest infestations of China's cotton crop and the high levels of spraying, the amount of loss to the cotton crop and the amount of loss that was abated due to spraying is high and exceeds that of grain (Table 2). Nationally, the Ministry of Agriculture's pest prevention teams estimate that cotton yields have been reduced by 5.3 to 14.0 percent due to pest infestations in the 1990s (column 2). The levels of loss were higher in some of the important cotton producing provinces, such as Hebei Province (column 4). In fact, the infestations from pest and the loss that such infestation potentially could cause are even more severe (rows 6 to 10). Had farmers not sprayed, cotton yields in China would have fallen nationally by 19 to 38.1 percent (columns 2); those in Hebei and Shandong Provinces would have fallen even more (columns 4 and 6). The larger "gain" (or, more accurately, avoid the loss) of cotton farmers when compared to those of grain farmers come from the fact that pests infestations are more serious and pesticide use are higher than those experienced by grain farmers. For example, pesticide use in cotton production was nearly 4 times as much as in rice (Huang et al., 2000a).

The data, in fact, are consistent with the observation that increasing pest populations have meant that farmers need to spray increasingly greater amounts of pesticides to control them (Table 3). Measured in constant prices, per hectare pesticide use on cotton rose nearly 300 percent in 2 decades (row 1). The rise in pesticide use grew faster than the rate of the use of other inputs. The share of pesticide cost in the total cost of production inputs rose from 12 to 13 percent in the early 1980s to more than 20 percent after the mid 1990s (row 2). China's cotton farmers spent more than $500 million annually on pesticides to control pest-related problems in the late 1990s (row 3).

What are the costs of spraying? Without accounting for the effect on human health or the environment, Huang et al.(2000b) demonstrate that the gains by farmers from the pesticide use are much higher than the costs farmers paid for the pesticide. Hence, there is a high "private" incentive for farmers to apply pesticide on crops, particularly on cotton crops.

The Spread of Bt Cotton

China has pursued a policy that has encouraged the release of Bt cotton varieties perhaps because of the high level of pesticide use and the possibility that pests are becoming resistant to popular types of pesticides. By almost all indications, cotton has become the most widespread and aggressive transgenic crop program for small holders in the world. In terms of sown areas, Bt cotton is the most extensively grown transgenic crop in China today. The official government estimates of Bt cotton area in 2000 ranged from 400 to 500 thousand hectares (personal communication with MOA's officials). During interviews with a number of industry analysts and executives, estimates had already reached 1 million hectares in 1999. Our estimates of Bt cotton area, which are based on interviews with provincial agricultural bureaus, extension officials, and seed companies, fall in the middle of the official and industrial estimates. Starting from only 2000 hectares in 1997, Bt cotton sown area grew to around 700 thousand hectares in 2000 (Huang et al., 2000a). By 2000, we estimate that farmers planted Bt varieties on 20 percent of China's cotton increase. Whatever the source of the estimates, the growth of Bt cotton areas has been remarkable in China in the last 3 years.

The expansion of Bt cotton across China, however, has not been even. For example, after being the only province to grow Bt cotton in 1997, cotton farmers in Hebei account for approximately 30 percent of the sown area in 2000, 220 thousand hectares. Shandong Province ranks second in Bt cotton sown area at 170 thousand hectares. In contrast, other provinces, particularly those with lower levels of cotton bollworm infestation, have very little or no area sown to Bt varieties.

Models and Estimation

Several economic studies have questioned whether current patterns of pesticide use are economically and socially efficient (e.g., Pimentel and Lehman. 1992; Pingali and Roger, 1995; Yudelman et al., 1998). Some studies show that the costs, both economic and social, related to pesticide use in crop production exceed the gains from the reduction of crop yield losses (Pingali and Roger, 1995). While studies of pesticide productivity are relatively common, few researchers have assessed farmer pesticide adoption behavior, and no study has been done on the productivity of varieties with built in pesticides such as genetically modified Bt varieties.

Damage Control Production Function

In our study, we use a production function approach to estimate the impact of pesticide use and Bt cotton variety adoption on crop productivity. It attempts to determine the value and impact on cotton production of two different types of variables: first, abatement inputs such as chemical pesticide use and/or host plant resistant varieties in particular Bt varieties; and second, traditional inputs such as fertilizers and labor. Ceteris parabus, the use of chemical pesticides and host plant resistant varieties does not increase yields per se. Instead their primary role is to abate damage or keep output from falling. In contrast, the use of inputs such as fertilizer and labor contribute to yield directly increases.

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

When working to model and empirically track the impacts of pesticides and Bt varieties on output, special attention needs to be given to the special nature of the inputs. In production function analysis, the effect of damage abatement inputs must be measured assessing the amount of yield or output that was "recovered" by the use of damage abatement inputs. Following the works by Headley (1968) and Lichtenberg and Zilberman (1986), a damage abatement function can be incorporated into the traditional models of agricultural production. However, unlike all but several previous works (including our own work on rice—Widawsky et al., 1998), we will include host plant resistant varieties into our analysis within the damage abatement approach. We do this primarily by allowing for the interaction between pesticides and Bt varieties.

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

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

where the vector X includes labor, fertilizer, other farm-specific factors that affect yields (such as the human capital characteristics of the farm household that are proxied by the household head's age and education level) and location-specific factors (a set of county dummy variables). The term, $G(Z)$, is a damage abatement function that is a function of the level of control agent, Z (in our case the pesticide used by the farmer to control pests during outbreaks). The abatement function possesses the properties of a cumulative probability distribution. It is defined on the interval of [0, 1]. When $G(.) = 1$, it means that there has been a complete abatement of crop yield losses due to pest related problems with certain high level of control agent, while when $G(.) = 0$, it means that the crop was completely destroyed by pest related damage. The $G(.)$ function is non-decreasing in Z and approaches one as damage control agent use increases. If we assume a Cobb-Douglas production function, $f(X)$, and if we assume that the damage abatement function, $G(Z)$, follows a Weibull, Exponential or Logistic specification, then equation (1) can be written as:

(2) $Y = a_0 \prod_i^n X_i^{ai} \, [\, 1 - exp(- Z^{e})]$, (Weibull)

(3) $Y = b_0 \prod_i^n X_i^{ki} \, [\, 1 - exp(- c\, Z)]$, (Exponential)

where a_0, a_i, e in (2), and b_0, k_i, c in (3) are parameters to be estimated. The i indexes inputs, including labor and chemical fertilizer. The variable Z represents pesticide use. The models in equations (2) and (3) could be estimated for Bt cotton and non-Bt cotton separately.

Because Bt cotton differs from non-Bt cotton mainly in the pest control efforts that farmers use to control bollworms, it is possible to explicitly model the interaction. To do so, we can pool data on Bt and non-Bt cotton to estimate a more general damage control production function with the following assumptions on the nature of the Bt and pesticide interactions:

(4) $e = e_0 + e_1\,Bt$

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

where *Bt* is a dummy variable with a value of 1 for Bt variety and 0 otherwise. The models (2) and (3) combined with the working hypotheses (4) and (5) are estimated by nonlinear methods. In order to compare the results from the traditional production approach, we estimate a Cobb-Douglas production function using OLS, where pesticide use and Bt cotton adoption are specified the same as other inputs such as labor and fertilizer.

Marginal impacts of pesticide use on cotton yield for the above models can be estimated as:

(6) $MP\ (Z) = a_0 \prod_i^n X_i^{ai}\ [exp(- Z^{e})\ e\ Z^{e-1}],$

(Weibull)

(7) $MP\ (Z) = b_0 \prod_i^n X_i^{ki}\ [\ exp(- c\ Z\ )\ (c)\ ],$

(Exponential)

The impacts of Bt cotton on the marginal products of pesticide use can be examined through the equations (6) and (7) by using the different values of the parameters associated with Bt and non-Bt varieties from equations 4 and 5). The optimal pesticide use level can also be estimated for both Bt and non-Bt cottons based on the assumption that the efficient use of pesticide requires that the value of its MP equals its price.

Finally, the impact of Bt cotton on the crop yield can be measured as:

(8) $DY = a_0 \prod_i^n X_i^{ai}\ [exp(- Z^{e})\ \ln (Z)\ Z^e\ e_1\ ],$

(Weibull)

(9) $DY = b_0 \prod_i^n X_i^{ki}\ [\ exp(- c\ Z\ )\ Z\ c_1],$

(Exponential)

Empirical specification and estimation of Pesticide use equation

The models specified above do not account for one potential statistical problem: the endogeneity of pesticide use in the production function. Since pesticides are applied in response to pest pressure, which are not controlled for in the analysis high levels of infestations may be correlated with lower yields. Hence, it is possible that the covariance of Z and the residuals of the production function is non-zero, a condition that would bias parameter estimates of the impact of pesticides on output. In other words, pesticides adopted by farmers may be endogenous to production and a systematic relationship among plant pests, pesticide use, and cotton yields may exist.[i] Because of the nature of potentially omitted variables and correlations, not accounting for the endogeneity could lead to a downward bias in the coefficient.

To avoid this possible econometric problem, we adopt an Instrumental Variable (IV) approach. To develop an instrument for pesticide application that is correlated with actual pesticide use but does not affect output except through its impact on pesticides, a pesticide adoption model is estimated first. The predicted values of the pesticide use can then be used in the estimation of models (2) and (3). As long as a set of variables in the pesticide adoption equation exists to explain pesticide use and these variables do not have any independent explanatory power on output, the IV approach should allow us to better examine the impacts of Bt and pesticides on cotton output and the interactions of these two pest control technologies.

To implement the IV identification strategy, we hypothesize that in addition to a number of control variables that are also in the yield equation (such as age, education and location dummy variables), farmer pesticide use depends on the profitability of pesticide use. Three measures are included to pick up this effect: the price of pesticides (*Price*), the perception by farmers of how severe his or her pest infestation problem is (*Yloss*), and the amount of information the farmer has about infestation from interactions with extension agents (*Extservice*). Although we have only a single cross section of households, large variations in the price of pesticides exist among the respondents, reflecting the differences in quality, pesticide prices at different times during the cotton growing season, and the pesticide composition. *Price* is the unit value price of pesticide, measured as the value of total pesticide use divided by the quantity used, a variable also was created to measure the farmer's expected profitability from pesticide use. During the survey, enumerators asked farmers to provide them with a percentage yield loss that they *typically* would expect to suffer from pest infestation should they not spray. We also asked the farmer about their meetings with extension agents that were charged with pest prevention. *ExtService* is an indicator variable measuring whether or not the farmer was visited by a local pest-prevention agent (ExtService = 1) or not (=0) during the crop year. Logically these variables meet the criteria of IVs and they pass the Hausman-Wu exclusion restriction statistical tests.

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

Pesticide= f (*Yloss, Price, ExtService; Variety Dummy; Age; Education; County Dummies*)

where the first three variables on the right hand side of equation (10) are the instruments, and the others are the control variables. More specifically, in equation (10), we include *Variety Dummy,* a dummy variable with a value equal to 1 when the farmer uses Bt cotton, and 0 otherwise. We also include *Age, Education,* and *County Dummies.* In equation (10), the dependent variable pesticide, is defined in terms of quantity (measured as kilograms per hectare). An alternative specification in terms of pesticide cost (yuan per hectare) generates similar results. Therefore, only the results from one of these 2 specifications are presented. The 2-equation system model is estimated using a three stage least squares estimating approach.

The Results

While the focus of the paper is on the impact of pesticides and Bt cotton varieties on yields, we begin with a brief discussion of the pesticide equation. In addition to the statistical importance of the estimation of the first stage equation, examining the determinants of pesticide use is interesting in its own right. After discussing the results of pesticide use equation, we then discuss the cotton yield functions.

Pesticide Use

The results of the pesticide equation demonstrate that the first stage of our model generally performed well in explaining pesticide use (Table 4, column 1). OLS versions of the same model (not shown) show that the model has a relatively high explanatory power, with adjusted R-square values that range between 0.50 and 0.60, levels that are reasonable for cross-sectional household data. The results of the alternative functional forms (also not shown) demonstrate that the results are robust, as are most of the results for the different versions of the model using alternative specifications of the dependent variable. Most of the signs of the estimated coefficients of the control variables are as expected.

Most importantly, the regression analysis illustrates the importance of Bt cotton in reducing pesticide use (Tables 4, column 1). The negative and highly significant coefficient on the Bt cotton variable, means that Bt cotton farmers sharply reduce pesticide use when compared to non-Bt cotton farmers. Ceteris paribus, Bt cotton use allows farmers to reduce pesticide use by 35.4 kilograms per hectare. Given that the mean pesticide use of non-Bt cotton producers is 60.7 kilograms per hectare (Table 1), the adoption of Bt is associated with a 58 percent reduction of pesticide use. Bt varieties, at least in the sample areas and during the years of their use by farmers that are included in the study, lead to significant pesticide reductions. In other words, with the same set of data, Huang et al. (2001) demonstrate Bt cotton adopters spray 67 percent fewer times and reduce pesticide expenditures by 82 percent.

Impacts on Cotton Production

Our analysis of the impact of Bt cotton and other pest control methods also shows the effect on cotton production, although the results are more sensitive to the methodological approach. To explore the importance of the choice of methodology, we first present the results that treat pesticide use and Bt cotton adoption as traditional inputs using a Cobb-Douglas functional form. We then turn to our non-linear estimate approach in which we analyze the effect of pest control efforts within a damage control production function framework. Following the discussion in the methodological section, we use two alternative functional forms of the damage abatement function.

The production function analysis generates results that are typical of household studies done on China's agricultural sector (Ye and Rozelle, 1994; Putterman and Ciacu, 1994; Li, 1999). In all of the specifications, we find strong and significant impact of human capital variables, age and education, on cotton output (Table 4, columns 2 to 5). The coefficients on the labor and fertilizer variables confirm that the output elasticities of both labor and fertilizer are low; our estimated labor elasticities are about 0.04 to 0.06. Farmers in our sampled areas apply 399 kilograms of fertilizer per hectare, one of the highest application rates in the world. Labor use also exceeds 500 man-days per hectare. Therefore, such insignificant marginal contributions of fertilizer and labor to cotton production may be expected.

The results of the Cobb-Douglas function approach indicate that although Bt varieties raise cotton yields, pesticide use is not effective in raising yields (Table 4, column

2). Although the descriptive statistics are statistically indistinguishable (i.e., the unconditional yields of Bt cotton users are statistically the same as the unconditional yields of non-Bt cotton users), when other inputs and human capital variables are accounted for, Bt cotton users get 15 percent higher yields (see the coefficient for the Bt cotton dummy variable in Table 4 column 2). The low t-ratio on the coefficient of the pesticide, however, can be interpreted to mean that the marginal impact of pesticide use in cotton production is zero when pesticide is treated as a traditional yield-increasing input.

Among the two alternative specifications of the damage control functions, the ones that use the Weibull and exponential damage control functional forms show similar results for the effect of Bt cotton (Table 4, columns 3 to 5). If these specifications reflect the true underlying technology, our results suggest that Bt cotton is effective in helping pesticides reduce the damage from pest infestations and keeping yields higher than they would have been without Bt adoption. In other words, Bt cotton increases the technical efficiency of cotton production.

The results of the models that treat pesticides as a damage abating input produce mixed results. In the model using the Exponential function, pesticides are seen to affect yield. In contract, the coefficient in the equation that uses the Weibull functional form has the wrong sign. In both cases, the marginal impact is small. If our data and econometric approaches are sound, one assessment of the results is that farmers are using so much pesticide, even when they adopt Bt cotton, that the marginal effect is near zero.

Using the parameters presented in Table 4, the associated output elasticities, average and marginal products of pesticide use, and optimal pesticide applications for both Bt and non-Bt cottons are computed and presented.[ii] While the point estimates of the marginal products and elasticities vary, the most notable result—for both Bt and non-Bt varieties, is the gap between actual and optimal pesticide use. In all cases, but especially for the case of non-

Bt varieties, farmers are using pesticides far in excess of their optimal levels. For example, in the case of the estimates that use the exponential functional form, Bt cotton users use 10 kilograms per hectare more than is optimal; non-Bt users use nearly 40 kilograms per hectare more.

Figure 1 shows the trend of cotton's marginal product value with respect to pesticide use evaluated at means of all non-pesticide variables. These results show both the overuse of pesticides and the superiority of Bt cotton in its ability to lead to lower levels of pesticide use. Increases in the value of an additional kilogram of cotton output approaches zero as pesticide use increases to a level above 20 kilogram per hectare for Bt cotton varieties under a Weibull specification; it approaches zero even more rapidly when using the parameters from the exponential function. For non-Bt cotton, the exponential function specification shows that the marginal product value of pesticide use approaches zero after the pesticide use level reaches 30 kilograms per hectare. These results illustrate not only that pesticides are being over used by both Bt and non-Bt users. If users were to use pesticides up to their optimal levels, Bt cotton users would use far lower levels of pesticides.

Concluding Remark

Intensive cultivation and broad adoption of fertilizer responsive varieties have led to widespread pest infestations in China and in every other developing country over the past several decades (Pingali, et al., 1997). The extent of pest-related diseases has grown by several times during the past two decades in China. Rising pest problems and the availability of relatively inexpensive pesticides as China's markets have developed have contributed to the use of pesticides in crop pest management. Although statistics are difficult to compare, China is most likely already the largest pesticide user in the world, and pesticide use is still rising. Among all the major crops in China, cotton producers have traditionally used pesticides in the most intensive ways. Hence, it is important to understand why and how cotton producers use pesticides and to explore how alternatives to pesticide use have performed in recent years.

One of the results of our work is that even without alternatives, cotton producers most likely could reduce pesticide use without affecting yields or profits. Although a discussion of why farmers overuse pesticides is beyond the scope of the paper, it is clear that such behavior is systematic and even exists when farmers use Bt cotton varieties. One thought is that farmers may be acting on poor information given to them by the pest control station pe[iii]rsonnel. In fact, such a hypothesis would be consistent with the findings of work on China's reform-era extension system in general (Huang et al., 2000d).

During the past decade or more, extension agents have had their salaries cut and have been forced to rely on income generated from sales of inputs to farmers, including, in no small way, farm chemicals. Hence, it may be that agents have an incentive to push farmers to apply more than the optimal amount of pesticide as a way to increase their sales and supplement their incomes. Such a hypothesis would also support the observations of foreign seed company managers who report that such agents often resist the spread of Bt varieties because of their lower requirement for pesticides. When farmers have adopted Bt, such agents also suggest that farmers apply pesticides in the later parts of the season, even though the seed companies agronomists believe such sprayings are unnecessary.

Our results show the impact of Bt cotton varieties on pesticide use, the effectiveness of pesticide's impact on yields, and its independent effect on yields. In other work, we have shown that the recent fall in the provincial use of pesticides in Hebei and Shandong Provinces can almost all be attributed to the spread of Bt cotton in these two areas. If the health and environment also improve with the fall in pesticide use, the benefits from extending Bt cotton exceed the production efficiency gains found here. In addition, unlike in work that denote treats pesticides and Bt cotton as damage abatement inputs, we find that Bt cotton users also get an independent increase in yields. Although Bt cotton is relatively new in China and the long run effect of Bt use in China is not known, it appears to be an agricultural technologies that improves both efficiency in production and the environment.

In terms of policies, our findings suggest that the government should invest the money necessary to spread Bt to other cotton regions and to other crops. The important caveat is that government investments in regulation of biotech will have to be increased to ensure that widespread use of Bt does not lead to the rapid development of resistance.

The second implication of these findings is that the government plant protection system does not appear to be meeting the goal of reducing pesticide use. This fits with anecdotal evidence that we picked up from seed companies and farmers that the plant protection people often recommend that farmers not use Bt cotton and they consistently recommended more pesticide applications than the seed companies that sell Bt cotton. One recommendation would be to suggest that the government separate the IPM activities and staff of the Plant Protection System from the pesticide sales activities and staff. Once this is accomplished, the government must give the extension service incentives to promote IPM and appropriate technology.

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Table 1. Summary statistics of Bt and non-Bt cotton production in sample households in China, 1999.

	All sample		Bt cotton		Non-Bt cotton	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Farm size (ha)	0.78	0.35	0.78	0.35	0.77	0.33
Cotton sown area (ha)	0.42	0.21	0.41	0.20	0.51	0.25
Cotton share in total crop sown area (%)	39	17	37	17	47	13
Age (years)	43.1	8.9	42.8	8.9	45.0	9.1
Education (years)	7.5	3.0	7.6	3.0	6.5	2.8
Yield (kg/ha)	3349	627	3371	584	3186	875
Cotton price (yuan/kg)	3.36	0.75	3.37	0.80	3.29	0.14
Ratio of phosphate fertilizer	0.30	0.20	0.31	0.20	0.23	0.14
Ratio of potash fertilizer	0.17	0.17	0.18	0.17	0.13	0.12
Fertilizer use (kg/ha)	399	195	407	200	339	147
Number of pesticide applications (times)	8.1	7.2	6.6	4.2	19.8	12.7
Amount of pesticide use (kg/ha)	17.5	28.9	11.8	13.7	60.7	60.5
Cost of pesticide (yuan/ha)	403	661	261	267	1465	1388
Pesticide price (yuan/kg)	34.5	46.6	35.9	49.4	23.9	8.0
Labor use (days/ha)	530	222	519	223	610	205
Number of observations (n)	382		337		45	

Note: The statistics in the table are from 282 households in 5 counties of Hebei and Shandong provinces. Some farmers use two or more than two varieties, including both Bt and non-Bt varieties.

Table 2. Official estimates of pest-related losses and losses abated by pest control efforts in China, 1990 to 1997.

	National		Hebei		Shandong	
Year	Grain	Cotton	Grain	Cotton	Grain	Cotton
	Proportion (%) of losses due to pest infestations					
1990	3.2	5.3	2.9	11.6	5.0	5.1
1992	2.0	14.0	3.3	39.9	3.5	17.0
1994	2.0	11.8	1.9	9.7	3.5	8.9
1996	2.1	6.2	2.2	13.2	3.3	5.9
1997	2.4	6.3	2.2	13.7	3.4	5.1
	Proportion (%) of losses to crop production abated by pest control efforts					
1990	7.6	19.0	6.6	32.6	10.1	21.5
1992	6.8	31.1	7.5	77.1	11.1	52.7
1994	7.2	38.1	6.9	43.8	11.4	43.5
1996	7.9	26.6	8.2	51.9	12.1	34.9
1997	9.3	29.1	8.6	73.2	12.5	31.9

Note: Actual crop production loss (a better term is "official estimate of crop production loss") is due to inability of pest control effort by farmers. Crop production loss abated from the pest is the avoided loss after the existing pest control effort in the farm field.

Source: Computed by authors based on the data from MOA, Agricultural Yearbook of China.

Table 3. Pesticide use in cotton production in China, 1980 to 1998.

	1980	1985	1990	1995	1998
Per hectare pesticide use (yuan at 1995 prices)	257	292	381	834	724
Share of pesticide cost in total material costs (%)	13	12	18	22	20
Total value of pesticide applied (million US$)	280	172	356	542	418

Note: Rural retail price index of pesticides is used to deflate the current value.
Source: State Economic Planning Commission and State Statistical Bureau.

Table 4. Estimated parameters for pesticide use and cotton yield using Two-Stage Least Squares and Damage Abatement Control Methods.

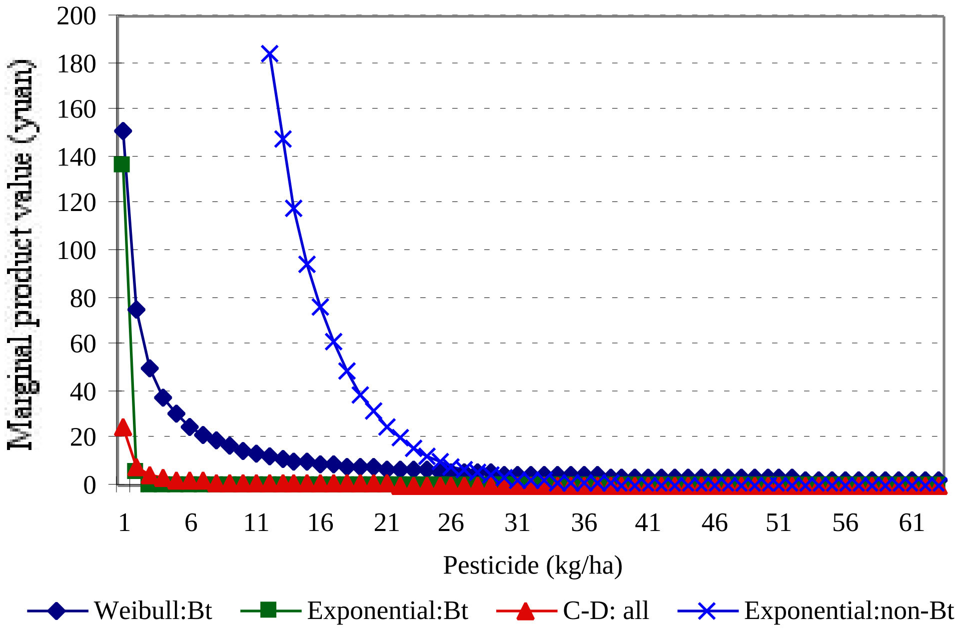
Exponential	Amount of pesticide use (kg/ha)	Cobb-Douglas function Ln (yield)	Damage control function Ln (yield)	
			Weibull	Exponential
Intercept	46.98 (9.24)***	7.23 (0.28)***	7.81 (0.28)***	7.20 (0.40)***
Perception of yield loss: Before flowering	0.04 (0.04)			
After flowering	0.15 (0.03)***			
Average pesticide price	-0.02 (0.03)			
Age	0.06 (0.14)	0.11 (0.05)**	0.12 (0.05)**	0.13 (0.07)*
Education	-0.67 (0.44)	0.01 (0.01)**	0.01 (0.01)**	0.01 (0.01)*
Labor		0.04 (0.03)	0.04 (0.03)	0.06 (0.04)*
Fertilizer		0.01 (0.02)	0.01 (0.02)	0.01 (0.03)
Pest management info. from extension agent (dummy)	-0.09 (0.09)			
Bt cotton variety (dummy)	-35.35 (4.07)***	0.15 (0.04)***		
Predicted pesticide		0.01 (0.01)		
Damage control function parameter estimates				
e_0 (pesticide parameter in Weibull model)			-0.05 (0.02)**	
e_{bt} (Bt variety parameter in Weibull model)			0.07 (0.02)***	
c (pesticide parameter in exponential model)				0.22 (0.09)***
C_{bt} (Bt variety parameter in exponential model)				5.96 (0.95)***

Notes: Ratios of phosphate and potash fertilizers are specified in linear rather than in log form. The figures in the parentheses are standard errors of estimates. ***, **, * denote significance at 1%, 5% and 10%, respectively. The model includes four county dummy variables to control for county-specific effects, but the estimated coefficients are not included for brevity.

Table 5. Estimated productivity measures of pest control management using alternative approaches.

	Cobb-Douglas	Weibull	Exponential
Bt cotton			
Average product	286	286	286
Marginal product	0.315	10.89	11.95
Elasticity	0.001	0.038	0.042
Actual pesticide use (kg/ha)	11.8	11.8	11.8
Optimal pesticide use (kg/ha)	0.34	4.20	1.20
Non-Bt cotton			
Average product	52.5	52.5	52.5
Marginal product	0.01	-	7.24
Elasticity	0.000	-	0.138
Actual pesticide use (kg/ha)	60.7	60.7	60.7
Optimal pesticide use (kg/ha)	0.094	-	21.24
Impact of Bt cotton on yield (kg/ha)	514	250	224

Notes: Productivity increases use parameters from Table 4. Elasticities, average products, marginal products, and optimal pesticide application levels are calculated using means of all variables.



Note: See note to Table 5 for description of calculation.

Figure 1. Marginal product values of pesticide use in cotton production.

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

[ii] The optimal use of pesticides is calculated by solving for the optimal level of pesticide use, given the price of pesticide and the value of its marginal product.