Genetically Modified Cotton and Farmers' Health in China

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This study provides the first evidence of a direct link between the adoption of a genetically modified (GM) crop and improvements in human health. Estimation of the impact of *Bacillus thuringiensis* (Bt) cotton adoption on pesticide use from data from a survey of cotton farmers in northern China, 1999–2001, showed that Bt cotton adoption reduced pesticide use. Assessment of a health-production function showed that predicted pesticide use had a positive impact on poisoning incidence. Taken together, these results indicate that the adoption of Bt cotton can substantially reduce the risk and the incidence of poisonings. *Key words*: Asia; China; biotechnology; pesticide; farmers; health; poisoning; genetically modified.

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Critics of biotechnology have made health, food safety, and environmental fears the centerpiece of their attacks. There is no evidence that anyone's health has been harmed by modifications resulting from biotechnology, but they imply that hidden scourges such as mad cow disease lurk in biotechnology-modified food and will some day harm us, the implication being that it is safer to use current technology than to take the risks associated with biotechnology. This implies that current technology is safe.

One component of the current technology for growing crops in developing countries is heavy use of chemical pesticides, which kill and sicken many farmers and farm laborers each year and cause debilitating sicknesses for years after exposure.[1–2] In China during the period 1992–1996, the last five years for which aggregate data are available, there were an average of 54,000 poisonings of farmers annually and approximately 490 deaths of farm workers or farmers by pesticide poisonings each year.[3] In addition, pesticides make their way to consumers as residues on fruits, vegetables, and grains and through contaminated water supplies. It is clear in many countries that the use of pesticides, which are the current alternative to biotechnology, carries many immediate as well as longer-term risks to human health.

The real choice for policymakers, farmers, and consumers is not between a technology that may have risks in the future and a completely safe technology. The real choice is between genetically modified crops that so far have proven safe but may be found to have some health and environmental risks in the future and conventional pest management technology that demonstrably is implicated in thousands of cases of sickness and hundreds of deaths each year.

To make this choice, however, policymakers need to know how serious the risks from pesticides are and whether the adoption of the specific types of biotechnology that are currently available will actually reduce pesticide used by farmers and, in turn, the number of poisonings. The main objective of this study was to measure the relationship between pesticide poisonings and the use of one specific product of biotechnology, cotton that is has been genetically modified (GM) with a gene from a soil bacterium, *Bacillus thuringiensis* (Bt), that is deadly to bollworms and other similar pests. The use of Bt cotton is dramatically reducing the use of insecticides by farmers in industrialized[4] and developing countries.[5] However, no-one has conclusively documented the links between use of Bt technology, insecticide use, and poisonings.

In previous papers using the data from a 1999 survey of 286 farmers,[5,6] we have documented the lower mean level of pesticide use and lower levels of reported poisoning by farmers who used Bt cotton compared with those who used conventional techniques. We did not explicitly model the relationship between Bt cotton adoption and poisonings in such a way that we could test the influence of Bt cotton use holding other important influences on poisoning constant. In the crop years 2000 and 2001 we increased our sample size to about 400 farmers in Northeastern China. Based on the data from three years and more provinces we are able to confirm the hypotheses suggested in the earlier studies that the adoption of at least some types of genetically-modified crops can reduce the risk of pesticide poisoning.

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TABLE 1. Pesticide Use on Key Crops in China, 1980–1998*

	Per Hectare Pesticide Cost (US$ at 1995 Prices)					
	Rice	Wheat	Maize	Cotton	Tomato	Cucumber
1980	11	3	1	31	NA	NA
1985	14	3	1	35	NA	NA
1990	16	5	2	46	45	56
1995	25	8	7	101	105	97
1998	25	9	7	88	136	129

Source: Huang et al.[5]

PEST CONTROL IN CHINA

In recent years pesticide use has been the main method of controlling insect pests in China. Both the active ingredients and the formulated pesticides are mainly produced by Chinese companies. Foreign suppliers have been limited by Chinese regulations to approximately 20% of the market. The pesticides are distributed to farmers by government input supply organizations and the extension service. The government extension service not only supplies the technology but also does scouting for pests and provides advice to farmers about when to spray and what to spray. At present the Chinese pesticide market is probably the largest in the world based on quantity used, and China competes with the United States for the highest-value market.[5]

More pesticide is applied per hectare to cotton than to any other major field crop, although the amount used is less than for most vegetable crops (Table 1). Government officials are aware of the dangers of pesticides and have put policies in place to reduce the worst dangers. For example, they banned the use of chlorinated hydrocarbons such as DDT, endosulfan, and BHC in 1983 to eliminate their impacts on the environment and their longer-term health risks. However, the government did not ban the use of some very dangerous organophosphate pesticides. Through the extension system the government has tried to promote integrated pest management practices with the goals of reducing pesticide use and using pesticides more effectively. Nevertheless, pesticide use continues to grow rapidly.

After the government banned the use of chlorinated hydrocarbons in the early 1980s, organophosphates were the main type of pesticide used to control bollworm. However, bollworms that were resistant to most organophosphates evolved and farmers had to shift to a new type of pesticide called pyrethroids. These pesticides were effective for a while against bollworm and had the added advantage of being relatively safe for the farmers that applied them. However, by the mid 1990s bollworms had developed resistance to the pyrethroids, also.

In 1997 *Bacillus thuringiensis* (Bt) cotton, representing an entirely new technique for controlling pests, was introduced to the farmers. This type of cotton had been genetically engineered to contain the Bt gene that produces a protein that kills many lepidoptera insects. This type of pest includes many serious pests of agricultural plants, including the bollworm (*Helicoverpa armigera*), which is the main cotton pest in northeastern China. Both the Chinese Academy of Agricultural Sciences and a joint venture between Monsanto, Delta, and Pineland and the Hebei Provincial Seed Company developed varieties of Bt cotton for farmers. Farmers found that Bt cotton gave much better protection against bollworm than chemical pesticides—it increased yields while reducing the costs of insect control, thereby increasing the farmers' net income.[5] As a result, farmers have adopted it rapidly (see Figure 1). In Hebei and Shandong, Bt cotton is grown on nearly all farms in the cotton-growing area. In the country as a whole at least 30% of the cotton area is planted with Bt cotton varieties.

IMPACT OF BT COTTON ON POISONING

The reduction in pesticide use due to the adoption of Bt cotton has been substantial. Huang et al.[5] documented the reduction in pesticide use with data from a 1999 survey of 286 farmers from Hebei and Shandong provinces. They also found that a far larger percentage of farm families who grew conventional cotton reported sickness due to pesticide use compared with those who used only Bt cotton. However, the total

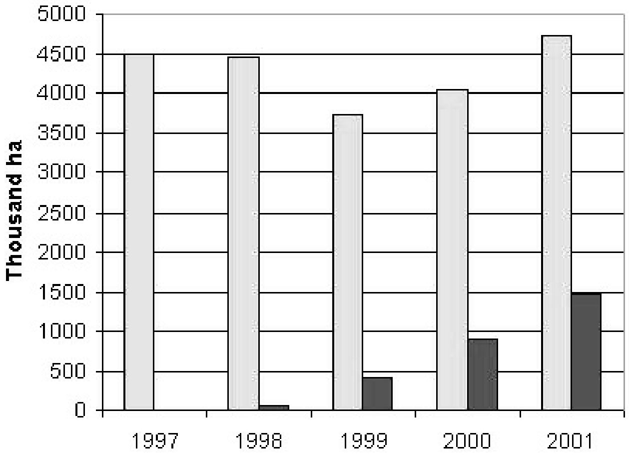

Figure 1—Total hectares of cotton grown (left, light bars) and Bt cotton grown (right, darker bars), 1997–2001.

TABLE 2. Environmental and Health Impact of Bt Cotton, 2000

	No. of Farmers	Pesticide Quantity* (Kg/Ha)	Poisonings† Reported by Farmers in 2000 Season: Required visit to: Hospital	Doctor	Self Treatment	Total	% Farmers Reporting Poisoning
Bt	316	18	2	3	23	28	9
Both Bt and non-Bt	61	29	0	6	10	16	26
Non-Bt	30	46	2	2	6	10	33

*Total pesticide (active + inert ingredients).
†Farmers were asked whether they had had headache, nausea, skin pain, or digestive problems when they applied pesticides.

number of cases was not large enough to econometrically test the relationship between Bt cotton use and pesticide use.

In 2000 and 2001 second and third surveys of Bt cotton's impact were carried out. The number of farmers was increased in 2000 by adding farms in the Henan Province. In 2001 the survey continued to interview farmers from Hebei, Shandong, and Henan and also added farmers from Anhui and Jiangsu. Farmers were chosen by first selecting counties in which Bt and conventional cotton were grown and then randomly choosing villages and farmers. The same questionnaire was used in 2000 and 2001 that had been used in 1999 except that in 2000 and 2001 the farmers were asked for more information about their experience with Bt cotton adoption over the preceding five years and about sickness from pesticide poisoning in the preceding five years.

Average pesticide use of Bt cotton growers and the numbers of poisonings of Bt and non-Bt cotton users in 2000 and 2001 were higher than in 1999. Farmers who grew only Bt cotton applied about 18 kg of formulated pesticide per ha, while farmers who grew only conventional cotton sprayed about 46 kg per ha (Table 2). Nine percent of the farmers who exclusively used Bt cotton reported poisoning, while almost a third of the farmers who exclusively used non-Bt cotton reported poisoning.

The linkages between Bt cotton adoption, reduction of pesticide use, and reduced poisoning incidence are further strengthened by the evidence presented in Tables 3 and 4. Table 3 categorizes the pesticides used by chemical type. The use of organophosphates showed the greatest decline. A number of organophosphates are rated highly for acute toxicity—category I in the Chinese and international systems, which rate pesticides from I to IV according to acute toxicity. Table 4 shows the toxicity levels and the numbers of users reporting poisonings for the insecticides that had caused the most poisonings during the preceding five years. Five of the top six pesticides, ranked by number of farmers reporting poisonings, were organophosphates. Furthermore, the most popular pyrethroid pesticide, cypremethrin, is a category II pesticide. It is not surprising, then, that a decline the amount of organophosphates used would result in a reduction in poisonings.

MODELING FARMERS' HEALTH

Our objective was to identify the impact of Bt cotton adoption on the incidence of poisoning of farmers holding other factors constant. It is hypothesized that the adoption of Bt cotton varieties affects poisoning incidence via two channels. First, adoption of Bt cotton varieties affects poisoning incidence by reducing the quantity of pesticide used. Pesticide use can have a direct impact on health.[1] Second, it can also affect health by reducing the number of times that farmers are exposed to pesticides through spraying. These two channels are likely to be closely correlated, but it may be possible to measure their separate impacts. A number of studies have modeled farmer's health as a production function. Health production-function theory states that health is commodity usually represented by mortality and morbidity. Here, incidence of poisoning is used as a proxy variable for morbidity. The health-production function is described as:

> Poisoning = f [pesticide use, adoption of Bt cotton, farmer human capital (education, age), farmer income, the environment (provincial dummies)]

Poisoning represents the number of times a farmer reports sickness from applying pesticide. Pesticide use is measured as the quantity of formulated pesticide

TABLE 3. Average Quantities (kg/ha) of Farmers' Pesticides Use by Type of Pesticide, 2000

	Average Quantity (kg/ha): Bt Varieties (*n* = 377)	Non-Bt Varieties (*n* = 90)	Decline in Use (%)
Organochlorines	1.6	3.9	58
Organophosphates	8.8	21.0	58
Amino–formicdacid esters	0.3	0.4	25
Pyrethroids	5.2	13.0	60
Organosulfates	2.8	6.0	53
Other insecticides	0.8	2.1	64
Fungicide	0.1	0.3	62
Herbicide	0.8	1.2	32
TOTAL	20.5	48.0	57

TABLE 4. Type and Toxicity Level sof Pesticides Causing Farmer Poisonings, 1995–2000

	Category Toxicity	Poisoning Cases
Organophosphates		
Chlordimeform	I	94
Parathion-methyl	I	65
Acephate	I	19
Carbofuran (furadan)	I	9
Phorate	I	9
Parathion	III	8
Monocrotophos	I	5
Pyrethroids		
Cypermethrin	II	12
Killingthrin 39	III	6

applied per household. The characteristics of the farm households are from our survey. The income variable may be related to health services in China, since the health system is privatizing. We control for environmental variables only by using provincial dummy variables.

The quantity of pesticide use in the above equation is a decision variable that depends on a number of variables. Farmers' decisions regarding how much pesticide to apply is a function of total area under cotton, area under Bt cotton, price of pesticides, severity of pest attack, the human capital of farmers, extension advice, and environmental variables. Specifically, the quantity of pesticide used is modeled as:

> Pesticide = f [total cotton area, area under Bt cotton, Pesticide price, severity of pest attack, farmer's human capital (education and age);extension advice; environmental factors (provincial dummies)]

The dependent variable is the quantity of pesticide used by a farm. Pesticide price is obtained as the total cost of all the pesticides applied to cotton divided by the quantity used. Severity of attack is the farmer's perception of the severity of the attack of bollworms in that year (defined as a dummy variable). Education and age of the farmer are from our survey. Data on extension advice were not available for all years so it was dropped. The dummy variable for the provinces gives a crude measure of the different environments. Cotton area is each farmer's total area of cotton, and Bt cotton is farmer's area under Bt cotton.

Two different empirical frameworks were used to model the relationship between farmer health and the adoption of Bt cotton. In the first approach, we used a logistic model to examine the impact of Bt cotton adoption on the likelihood of a farmer's becoming sick from pesticide poisoning. In the other approach, we used the Poisson regression model to analyze the impact of Bt cotton use on the number of pesticide-related poisoning incidents.

The Logit Framework

The logit framework models the relations between the likelihood of an individual farmer's becoming sick from pesticide poisoning and the socioeconomic and farm characteristics of the respondent. In order to implement the model, a binary dependent variable poisoning is defined as follows:

> Poisoning = 1 if the farmer i became sick at least once from pesticide during the year, and 0 otherwise

The empirical model assumes that an individual farmer's probability of becoming sick from pesticide use, P_i, depends on a vector of independent variables (X_{ij}) associated with farmer i and variable j, and a vector of unknown parameters β:

$$P_i = F(Z_i) = F(\beta X_i) = 1/[1+\exp(-Z_i)]$$

where:

$F(Z_i)$ = the value of logistic cumulative density function associated with each possible value of the underlying index Z_i;

P_i = the probability that a farmer becomes sick from pesticide use, given the independent variables X_{ij}.

In the above equation, βX_i is a linear combination of the independent variables so that

$$Z_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_k X_{ik} + \varepsilon_i$$

where:

Z_i = unobserved index level or the logarithm of the odds ratio of the i^{th} observation;

x_{ij} = j^{th} attribute of the i^{th} respondent;

β = parameters to be estimated;

ε = random error or disturbance term.

For empirical analysis, the following equation is estimated:

> Poisoning = f [pesticide use, adoption of Bt cotton, farmer human capital (education, age), farmer income, the environment (provincial dummies)]

Since some of the variables on the right-hand side of the above equation also influence the quantity of pesticide used, the estimated coefficient of pesticide is likely to be biased. To control for this problem, we first use OLS (ordinary least square) to estimate the pesticide equation model. The predicted pesticide quantity obtained from this model is then used as an explanatory variable in the logistic equation. In addition, in some specifications of the health production model we used the Bt cotton variable again because the number of times sprayed might have an impact directly on farmers apart from the quantity of pesticide used.

TABLE 5. Estimated Coefficients of the Pesticide-use Model: First-stage Regression

Variable	Coefficient	Standard Error	*t*-Ratio
Intercept	72.20	7.55	9.56
Total cotton area	5.64	0.82	6.91
Area under Bt cotton	–5.57	0.81	–6.87
Pesticide price	–0.75	0.17	–4.38
Heavy Incidence of pest attack	13.08	7.31	1.80
Dummy for Henan Province	–23.59	7.58	–3.11
Dummy for Shandong Province	–29.22	7.71	–3.79
Dummy for Anhui Province	90.64	8.72	10.39
Adjusted R^2		0.47	
F-Statistic of model significance		79.39	
Degrees of freedom		7	

Note: Dummy variable for Jiangsu Province is excluded from this estimation.

After eliminating the statistically insignificant variables from the right hand side, the following pesticide use equation was estimated using OLS data:

$$\text{Pesticides} = \beta_0 + \beta_1 \text{ Henan} + \beta_2 \text{ Shandong} + \beta_3 \text{ cotton} + \beta_4 \text{ Bt cotton} + \beta_5 \text{ Pesticide price} + \beta_6 \text{ severity}$$

The predicted pesticide quantities were then used as an explanatory variable in the logit model.

Poisson Regression Model

The logistic model above is unable to differentiate between single and multiple incidences of pesticide-related poisoning. Some farmers were victims of poisoning more than once. It is entirely possible that as a result of adopting Bt cotton, a farmer was able to reduce the number of times he or she became sick from poisoning. The dependent variable in the logistic model is unable to capture this reduction in the incidence of poisoning associated with Bt cotton adoption. In order to account for multiple poisoning incidences, a Poisson regression model was estimated to examine the impact of Bt cotton adoption on poisoning incidence. In the Poisson regression framework, the expected number of poisoning incidences is modeled as a function of pesticide quantity, adoption of Bt cotton, and other farm/farmer characteristics. Specifically, the Poisson model stipulates that the number of poisoning incidence for farmer i follows a Poisson distribution with a conditional mean (μ_i) that depends on pesticide use, adoption of Bt cotton, and other farm/farmer characteristics. Formally, the model is specified as follows:

$$\mu_i = E(\text{number of poisoning cases} \mid X) = \exp(\beta X_i)$$

where X_i represents the same set of explanatory variables used in the logit model and corresponds to farmer i, and β is the parameter vector.

EMPIRICAL RESULTS

The object of this study was to examine how pesticide poisoning is affected by the adoption of Bt cotton. In areas where only Bt cotton is grown, we do not get any variation in the Bt cotton area to examine its impact on the pesticide-related incidence of poisoning. Therefore, in the econometric analysis we exclude those provinces when only Bt cotton was produced. For instance, farmers in Hebei province produced only Bt cotton during 1999–2001. Therefore, we excluded all observations from Hebei province for those years. For the same reason, 2000 and 2001 observations from Shandong province were also excluded from this study.

As a result, the sample used in the study consisted of cotton growing farm households from four provinces as follows: for 2001, 79 farmers from Anhui, 121 farmers from Jiangsu, and 81 farmers from Henan; for 2000, 147 farmers from Henan; and for 1999, 183 farmers from Shandong. In total, there were 611 observations in the sample used for this study.

The estimated coefficients of the pesticide use equation, standard error, and *p* values are presented in Table 5. All independent variables are statistically significant at the 0.05 level except one. The adjusted R^2 was 0.47, which is reasonable given that the results are based on cross-section data. As we expected, the sign of Bt cotton was negative and statistically significant, which means that an increase in the area under Bt cotton, holding total cotton area constant, reduces the quantity of pesticides used. On the other hand, the sign of cotton is positive, which implies that an increase in the total area under cotton leads to increased use of pesticides. Average mixed pesticide price has the expected negative impact on quantity of pesticides use, which indicates that higher pesticide prices lead to less pesticide use. The variable for the severity of the pest attack is positive and significant at the 0.10 level.

In this model, it is possible that the area under Bt cotton is endogenous in the sense that it depends on other independent variables and is correlated with the model error term. We explored this possibility by regressing the area under Bt cotton on pesticide price and farmers' economic and demographic attributes. However, none of the explanatory variables was found to be statistically significant. We also computed Hausman's[7] test for endogeneity of area under Bt cotton. To implement this test, we regressed area under Bt cotton on pesticide price and farm/farmer characteristics. The predicted area under Bt cotton was then used as an additional independent variable in the pesticide use equation. The *t* ratio of the predicted Bt cotton area was –1.13, which gave an F statistic (the square of the *t* ratio

TABLE 6. Predicting Probability of Poisoning: Logistic Model

Variable	Estimated Coefficient	Standard Error	*t* Ratio	*p* Value	Marginal Effect
Constant	–1.0408	0.7209	–1.44		NA
Pesticide quantity (predicted)	0.0096	0.0047	2.05	0.04	0.0023
Area under Bt cotton	–0.0048	0.0026	–1.85	0.07	–0.0011
Age of farmer	–0.0063	0.0096	–0.65	0.51	NA
Education	–0.0793	0.0322	–2.46	0.01	–0.0196
Poor health condition	0.7518	0.3684	2.04	0.04	0.1859
Province dummy (Henan)	0.6714	0.3012	2.23	0.03	0.1703
Province dummy (Shandong)	0.6961	0.3267	2.13	0.03	0.1722
Province dummy (Anhui)	–0.5812	0.5817	–1.00	0.32	–0.1437
Log likelihood (LL) function	–358.08				
Restricted LL function	–438.26				
Likelihood ratio test for model significance	160.35				
Degrees of freedom	8				
McFadden's R^2	0.18				

Note: Marginal effects are computed for coefficients that are significant at 10% or lower level.

in this case) of 1.28. This F statistic (with appropriate degrees of freedom) is equivalent to the Hausman's test result.[8] Using appropriate degrees of freedom, we could not reject the null hypothesis that area under cotton is not endogenous (i.e., there is no evidence of endogeneity for the variable area under Bt cotton).

The estimated coefficients along with *t* ratios from the logit model are presented in Table 6. The goodness of model fit can be evaluated by the chi-square statistic of overall model significance. Given the estimated values of the unrestricted and restricted (i.e., all coefficients other than the intercept) log-likelihood functions (–358.08 and –438.26, respectively), the estimated log-likelihood ratio–based chi-square statistic is 160.35, which clearly exceeds the 95% critical value of the test statistic with 8 degrees of freedom. This indicates that that the model has significant explanatory power. Another goodness-of-fit measure is McFadden's R^2, which is obtained as $1 - LL_R/LL_U$, where LL_U and LL_R are values of the unrestricted and restricted (i.e., all slope coefficients are zero) log-likelihood functions. The estimated value of McFadden's R^2 is 0.143, which is quite reasonable for cross-sectional data.

The coefficient of the (estimated) pesticide quantity is positive and statistically significant at the 0.05 level. This confirms our hypothesis that pesticide use is strongly and positively associated with poisoning. It therefore follows that adoption of Bt cotton, which reduces the quantity of pesticide use, also reduces the likelihood of getting sick from pesticide poisoning. Further, the coefficient of Bt cotton is negative and significant at the 0.10 level. This implies that increases in Bt cotton adoption reduce the probability of getting sick from pesticide poisoning. Since the effect of Bt cotton through the quantity of pesticide sprayed is picked up by the pesticide quantity, this variable is picking up the added impact of Bt cotton on the number of times farmers have to spray. Farmers who have to spray more times, holding quantity constant, will be exposed more to pesticides and thus be more likely to be poisoned. The positive sign on the dummy for poor health indicates that these farmers have a greater likelihood of getting sick from pesticide poisoning than farmers in good health. Education, however, reduces farmers' probability of poisoning. The statistically insignificant coefficient of the age variable suggests that probability of poisoning is not related to variations in age.

The marginal effect of Bt cotton adoption on the probability of poisoning incidence works through two channels. First, adoption of Bt cotton reduces pesticide use and thereby lowers the chances of poisoning. This is given by

$$\frac{\partial \Pr(\text{poisoning})}{\partial \text{pesticide}} \; \frac{\partial \text{pesticide}}{\partial \text{Bt}} .$$

The other effect works through the coefficient of Bt cotton in the logit equation. This is given by the direct partial derivative of the dependent variable with respect to Bt cotton, holding pesticide quantity unchanged. Therefore, the marginal effect of Bt cotton adoption on the probability of poisoning is given by:

$$\text{Marginal effect} = \frac{\partial \Pr(\text{poisoning})}{\partial \text{pesticide}} \; \frac{\partial \text{pesticide}}{\partial \text{Bt}} + \frac{\partial \Pr(\text{poisoning})}{\partial \text{Bt}} .$$

Using the above formula, the marginal effect of Bt cotton adoption can be obtained as follows. The derivative $\partial \Pr(\text{poisoning})/\partial \text{pesticide}$, evaluated at mean values of other variables, is 0.0023. From Table 5, $\partial \text{pesticide}/\partial \text{Bt}$ is –5.57. Finally, the derivative of poisoning with respect to Bt cotton in the poisoning equation is –0.0011. Combining, we obtain the marginal effect of Bt area is –0.014. This result can be interpreted as follows: as a farmer devotes one more mu (1/15 of a

TABLE 7. Model Fit: Prediction Success

	Predicted		
Actual	0	1	Total
0	278	59	337
1	86	188	274
Total	364	247	611

hectare) of area to Bt cotton, the probability of that farmer's becoming sick from poisoning decreases by 1.4%. Since all coefficients involved in the estimation of this marginal effect are statistically significant, this estimated marginal effect is also statistically significant.

The results of Poisson modeling of the poisoning incidence are listed in Table 8. The likelihood ratio based the chi-square statistic of the overall model significance is 167.16, which far exceeds the 95% critical value of the test statistic with 8 degrees of freedom. This indicates that the model has significant explanatory power. Further, the Pearson R^2 (0.15) and the deviance R^2 (0.14) are quite reasonable for cross-sectional data. As in the case of the logit specification, the independent variables have the expected signs and all coefficients except age are statistically significant at the 0.10 level. Consistent with our expectations, coefficients of pesticide quantity and poor health increase the incidence of poisoning, while the area of Bt cotton and education levels reduce the incidence of poisoning.

Using reasoning similar to that used for the logit model, the marginal impact of Bt cotton adoption on the expected poisoning incidence can be obtained as follows.

Marginal effect =

$$\frac{\partial E(Y|x)}{\partial \text{pesticide}} \frac{\partial \text{pesticide}}{\partial Bt} + \frac{\partial E(Y|x)}{\partial Bt}$$

where Y be the number of poisoning cases.

Using $\partial E(Y|x)/\partial$pesticide equal to 0.0022 (from the estimated model), ∂pesticide/∂Bt equal to –5.57, and the partial derivative of the Poisson regression equation with respect to Bt area equal to –0.0007, the marginal effect of the Bt cotton area is obtained as –0.013. This result may be interpreted as follows: every 100 mu increase in area devoted to Bt cotton reduces the expected number of pesticide poisoning by 1.3 cases.

These econometric results provide clear evidence that the adoption of Bt cotton has a very important impact on reducing pesticide poisoning in China. It is consistent with the evidence from earlier studies, which indicated the mean pesticide use of adopters of Bt cotton was lower than that of users of conventional cotton and that adopters of Bt cotton reported less pesticide poisoning.

CONCLUSION

This study provides some of the first econometric evidence of the link between the adoption of a GM crop and improvements in human health. We modeled the linkage as a health-production function with farmers' reports of poisonings as the dependent variable and pesticide use, farmers' characteristics, and environment as independent variables. We hypothesized that the main impact of Bt cotton on poisoning would be through its impact on pesticide use. Therefore, we first estimated the impact of Bt cotton adoption on pesticide use with data from three surveys of cotton farmers in northern China. Our estimates showed that Bt cotton use reduced the quantity of pesticide applied. We then estimated the health-production function and found that predicted pesticide use had a positive impact on poisoning. In addition, we included a Bt cotton variable to try to capture any separate impact that it had on poisoning. Our hypothesis was that the

TABLE 8. Predicting Number of Poisonings: Poisson Model

Variable	Estimated Coefficient	Standard Error	*t* Ratio	*p* Value	Marginal Effect
Constant	–0.9799	0.3166	–3.10		NA
Pesticide quantity (predicted)	0.0028	0.0010	2.73	0.01	0.0022
Area under Bt cotton	–0.0009	0.0050	–1.72	0.08	–0.0007
Age of farmer	–0.0029	0.0050	0.58	0.56	NA
Education	–0.0201	0.0116	–1.73	0.08	–0.0163
Poor health condition	0.3608	0.1750	2.06	0.04	0.2917
Province dummy (= 1)	0.1146	0.0411	2.79	0.01	0.0901
Province dummy (= 2)	0.06019	0.3262	0.18	0.85	NA
Province dummy (= 4)	–0.1444	0.1843	–0.08	0.94	NA

Value of likelihood function	–773.31
Restricted likelihood function	–856.89
Likelihood ratio test for model significance	167.16
Degrees of freedom	8
Pearson R^2	0.15
Deviance R^2	0.14

Note: Marginal effects are computed for coefficients that are significant at 10% or lower level.

pesticide-use variable, which is the quantity of pesticide used, might not pick up all of the exposure impacts. Bt cotton did have a small negative impact on poisonings in addition to reducing pesticide use.

Taken together these results indicate that the adoption of Bt cotton will significantly reduce the risk and the incidence of poisonings. We first calculated the marginal impact of one more mu of Bt cotton use on the probability of farmers' having pesticide poisoning using the logit specification of the health function. We found that an increase in one mu reduces the probability by 1.4%. Using data from the Poisson specification, we calculated that the marginal decrease in the number of poisonings due to increasing Bt cotton adoption by one mu was 0.15.

This evidence strongly suggests that when assessing the risk of GM crops policymakers should put more weight on reducing the well-documented risks of pesticide poisoning than on the speculative but so far unsubstantiated health risks to consumers and farmers from the consumption of GM crops. It also suggests that the recent decisions of Indonesia and India to adopt Bt cotton technology are justified in terms of reducing farmers' health risks and that other cotton-growing countries should also consider using this technology.

The evidence also suggests that policymakers should put high priority on other ways to reduce the use of pesticides, for example, integrated pest management (IPM), which could also reduce farmers' pesticide use. IPM is clearly needed in China, because even with Bt cotton varieties, farmers spray far more pesticide than they need for good pest control.[5] Thus, it appears that IPM should be encouraged by the government to complement farmers' decisions to adopt Bt cotton.

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