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Bt Cotton in China: Are Secondary Insect Infestations Offsetting the Benefits in Farmer Fields?

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Abstract

The area sown to *Bt* cotton has expanded rapidly in China since 1997. It has effectively controlled the bollworm. However, in recent years, concern has surfaced about the emergence of secondary insect pests, particular mirids, in *Bt* cotton fields. This study measures the patterns of insecticide use based on farm-level from 1999 to 2006, the analysis demonstrates a rise in insecticide use to control mirids between 2001 and 2004, secondary insect infestations is largely related to the rise of mirids, but this rising did not continue in more than half of sample villages studied in 2004-2006. Moreover, the increase in insecticide use for the control of secondary insects is far smaller than the reduction in total insecticide use due to *Bt* cotton adoption. Further econometric analyses show that rise and fall of mirids is largely related to local temperature and rainfall.

Key words: *Bt* cotton, secondary insect, mirid, China

INTRODUCTION

Bt cotton has significantly reduced insecticide use at the farm level in both developed and developing countries. Researches in the United States (e.g., Perlak *et al*. 2001), Mexico (Traxler *et al*. 2001), South Africa (Ismael *et al*. 2001), China (Huang *et al*. 2002a; Pray *et al*. 2002) and India (Qaim and Zilberman 2003; Bennett *et al*. 2004) find strong evidence that *Bt* cotton adoption sharply reduces the use of insecticides by farmers and increases their productivity.

Despite the nearly incontrovertible evidence of the farm-level benefits from the use of *Bt* cotton during its first decade of adoption, there is concern that there will be an emergence of secondary insect populations in the fields of farmers that use *Bt* cotton. While *Bt* cotton has been effective in reducing the population of bollworms, because its toxicity spectrum is relatively narrow, affecting only one type of insect pests (*Lepidoptera*) instead of the much broader array of pests (and beneficial insects) that typically are killed by traditional chemical insecticide alternatives, it is possible that the use of *Bt* cotton and the associated lower levels of conventional insecticide spraying create a safer environment for other, non-bollworm insects. If so, there is the possibility that damage caused by secondary insects could offset some or all of the benefits that *Bt* cotton has generated. In fact, Wu and Guo (2005) show in laboratory studies that *Bt* cotton reduces the populations of some insects (e.g., the bollworm, small looper, cotton bollworm larval parasitoid), but not oth-

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ers (e.g., cotton aphids, mirids, turtle beetles). Other studies show that the populations of secondary insect pests, such as mirids and beneficial insects which control certain other pests can be higher in *Bt* cotton fields than in non-*Bt* cotton fields (Wu *et al.* 2002; Men *et al.* 2005). Depending on the severity of the problem and resulting insect population dynamics, it is possible that the emergence of secondary insects can be moderately to highly destructive.

Despite the danger of the rise of secondary insects, there has been relatively little research attention accorded the problem in the past, including in China. In 2004, however, researchers noted during their field surveys (and in their experimental fields during earlier years, Wu *et al.* 2002) the rise of spraying by farmers for secondary pests. In particular, there was a perception that the presence of mirids, an insect pest of the cotton plant, had increased. Although there were reports of mirids in China's cotton fields during the 1950s (Chu and Meng 1958; Chu 1960; Ting 1957, 1964), during the late 1980s and 1990s, a time when farmers were spraying extremely high levels of chemical insecticides (on average spraying more than 20 times per year), mirids were rarely mentioned by farmers or government entomologists during the early period of the adoption of *Bt* cotton. Because of the coincidence in timing between the reemergence of mirids and the expansion of *Bt* cotton, one natural hypothesis is that the two are connected and that it is possible their rise could offset the efficiency and health gains produced by *Bt* cotton. While there are laboratory and in-field agronomic experiments that connect the two, Wu *et al.* (2002) also points out that the higher mirid population, which they observed in their field trails are likely, at least in part, to be due to the level and inter-temporal distribution of temperature and rainfall during the cotton-growing season (June, July and August). In addition, there has never been a field-level study conducted in the fields of farmers that not only seeks to assess the role of *Bt* cotton in the rise of secondary insects, but also tries to measure the magnitude of the impact of the rise of secondary insects (versus the effect of *Bt* cotton adoption) on the productivity, income and health of farmers, if there is one. In fact, even outside of China, previous work on this topic has mainly focused on bollworm resistance to *Bt* cotton in both laboratory and in-field agronomic trails (e.g., Bates *et al.* 2005); there are few, if any, studies that seek to examine the impacts of *Bt* cotton on secondary insects in farmer fields, especially over a longer period of time (such as 5 or more years).

The overall goal of this study is to assess the dynamic nature of insecticide use over time in the fields of China's cotton-producing farmers and examine causes of any measured changes, especially due to the rise of secondary insect populations. The paper is organized as the follows. In the second and the third sections, survey data and descriptive statistics from the survey are discussed. The methodology for testing the hypothesis that *Bt* cotton use and insecticide use to control secondary insects (focus on mirids) are connected is presented in the fourth section. The final section presents the results and provides a discussion on the implications of the results.

While the link between the adoption of *Bt* cotton and rise of secondary insects is of interest to all nations that are currently or may be using *Bt* cotton, China is an interesting case for several reasons. First, ten years have elapsed since the initial commercialization of *Bt* cotton. Insects, both bollworms and other types, have always been considered cotton pests. Second, early studies show a significant reduction of insecticide uses in *Bt* cotton, but recent rises in insecticide use have led to the debate on the implications of *Bt* cotton on secondary insect population. Finally, this fairly unique set of circumstances occurs in a number of villages in which the authors have been collecting farm-level data since 1999.

DATA AND SAMPLES

The primary data used in this study is from a database established by the Center for Chinese Agricultural Policy (CCAP) on genetically modified crops in China. The database in early years has been used by researchers to assess the efficiency of *Bt* cotton relative to conventional cotton varieties in China (e.g., Huang *et al.* 2002a, b, 2003; Pray *et al.* 2001, 2002). By 2007, CCAP's database included five rounds of intensive farm household surveys that focus on *Bt* cotton production. The surveys cover 1999, 2000, 2001, 2004 and 2006. In each successive year, the CCAP survey team increased the sample size and coverage as the use of *Bt* cotton spread throughout China. The surveys cover 44 villages in 6 provinces, including Hebei (5 rounds of surveys in 2 villages; 3 rounds in 2 villages), Shandong (5 rounds in 2 villages; 3 rounds in 2 villages; 2 rounds in 2 villages), Henan (4 rounds in 4 villages; 1 round in 6 villages), Anhui (3 rounds in 2 villages; 2 rounds in 2 villages; 1 round in 4 villages); Jiangsu (1 round in 8 villages); and Hubei (1 round in 8 villages).

Villages and households that were surveyed were randomly selected. In each village about 25 to 30 farm households (the number varying with the size of the village) were randomly selected by the survey team from a comprehensive list of all farming households in the village, which was provided by the local household registration office. Each farmer was interviewed by trained enumerators from CCAP's survey team for about 2-3 hours using recall enumeration techniques that are standard in the economics literature. The information on *Bt* and non-*Bt* cotton production, both inputs and output, is available on a plot-by-plot basis.

To assess the *changing* pattern of insecticide use over time in the fields of the sample farm households and examine the causes of the *changes*, the analysis can only draw on sample villages that were surveyed in at least 2 periods and continued in 2006. Because of this, the analysis does not consider data from the 26 villages that were visited only once (6 villages from Henan; 4 villages from Anhui; 8 villages from Jiangsu; 8 villages from Hubei), and 2 villages from Shandong that were not visited in 2006. Hence, the observations from all of the villages in which enumerators visited at least twice and all visited in 2006 (that is, 16 villages from 4 provinces, Hebei, Shandong, Henan, and Anhui) are included in this study. In total, the sample includes information from 522 household observations that planted *Bt* and non-*Bt* cotton on 2 762 plots.

INSECTICIDE USE ON THE FIELDS OF CHINA'S COTTON FARMERS

As found in previous work on *Bt* cotton in China (e.g., Huang *et al*. 2002a, 2003), one of the main outcomes for farmers that adopt *Bt* cotton is the sharp reduction of insecticides when compared to non-*Bt* cotton farmers (Table 1). Firstly, we compare total insecticide use (columns 1 to 5) by farmers within the same villages (e.g., row 4 vs. row 11; row 6 vs. row 12; row 7 vs. row 13; row 8 vs. row 14) and insecticide use on *Bt* cotton plots with non-*Bt* cotton plots (row 1 vs. row 10), and find that the use by farmers adopting *Bt* cotton is sharply (and significantly in a statistical sense) less in all cases.

Data across time on insecticide use for each set of villages (that are examined by looking across each row of Table 1) show that the trend in some, although not all, of the sample villages rises in recent years. For example, from 1999 to 2006 total insecticide use on *Bt* cotton rises on the plots of farmers in Hebei-Xinji (from 5.7 to 36.3, row 2) and all *Bt* cotton plots sample (from 11.5 to 24.5, row 1). Hence, it may be that the jumps in these figures on total insecticide use are behind some of the concerns that there are rising pressures from secondary insects.

It should be noted, however, if secondary pests are the problem, the data are not consistent with this phenomenon happening everywhere. In the two villages in Shandong-Liangshan (row 5) and the four villages in Anhui (row 8 and row 9) in the period of 2001-2006, both the amount of total insecticide use fell. Hence, there is mixed evidence from the descriptive statistics on total insecticide use that there is a secondary insect problem emerging in China today.

Detail information elicited by enumerators on the type of insecticide and the primary target insect in *Bt* cotton production is available in CCAP's recent four rounds

Table 1 Total insecticide use on plots cultivated by farmers producing *Bt* and non-*Bt* cotton production in China, 1999-2006[1]

Location of villages (province-county)		Total insecticide use (kg ha^{-1})				
		1999 (1)	2000 (2)	2001 (3)	2004 (4)	2006 (5)
Bt cotton plots	(1)	11.5	20.8	24.1	23.4	24.5
Hebei-Xinji	(2)	5.7	21.5	16.7	30.6	36.3
Hebei-Shenzhou	(3)	5.6	5.7	-	-	18.9
Shandong-Xiajin	(4)	17.2	33.4	-	-	27.1
Shandong-Liangshan	(5)	15.4	20.9	19.0	10.8	11.2
Henan-Taikang	(6)	-	24.0	13.3	27.6	19.9
Henan-Fugou	(7)	-	11.7	13.8	19.2	24.7
Anhui-Dongzhi	(8)	-	-	46.5	28.6	27.5
Anhui-Wangjiang	(9)	-	-	45.0	30.6	30.6
Non-*Bt* cotton plots	(10)	77.5	47.3	64.1	37.8	45.4
Shandong-Xiajin	(11)	77.5	-	-	-	-
Henan-Taikang	(12)	-	44.7	37.7	42.6	35.1
Henan-Fugou	(13)	-	52.7	35.2	23.6	65.2
Anhui-Dongzhi	(14)	-	-	93.7	76.1	-
Anhui-Wangjiang	(15)	-	-	82.6	30.5	-

[1] Authors' surveys.

of surveys (2000, 2001, 2004 and 2006), which also provides mixed evidence of rising secondary insects (Table 2). The data presented in Table 2 exclude figures in 1999 because we are not able to analyze details of insecticide use for controlling major secondary insects such as mirids in CCAP's first round of surveys. As Table 2 shows, while spraying for bollworm has fluctuated over time on *Bt* cotton-producing plots in all villages (columns 1 to 4, rows 1 to 7), the rise in total insecticide use in sample villages might be due to increased spraying for secondary pests (columns 5 to 8).

However, as in the case of total insecticide use, there also are sets of villages (on the *Bt* cotton-producing plots in two Shandong-Liangshan and on the *Bt* cotton-producing plots in the villages in Anhui) in which the level of insecticide for secondary pests fell (rows 3, 6 and 7). Moreover, even in villages in which the level of insecticides for secondary insects rose in the period of 2000 to 2006, the rise has not been monotonic (as might be expected if secondary pest rose with the expansion of *Bt* cotton adoption). For example, between 2004 and 2006 insecticide use on secondary insects fell on the *Bt* cotton-producing plots in the two sample villages in Hebei-Xinji and in the two villages in Henan-Taikang.

While the case for the linkage between the rise of *Bt* cotton adoption and secondary insects is far from certain when examining insecticide use on all secondary insects, the case for a linkage between the expansion of *Bt* cotton and a particular secondary insect, mirids, is stronger (Table 2, columns 9 to 12). In fact, in the early years of adoption of *Bt* cotton (1999 and 2000, the third and fourth years after the initial commercialization) farmers did not spray at all for mirids. This is despite the fact that during the 1950s and 1960s there was considerable spraying for mirids by cotton producers in China (Chu and Meng 1958; Chu 1960; Ting 1957, 1964). The first spraying for mirids in our survey occured in 2001 on the plots of the sample farmers in Henan and Anhui (rows 4 to 7). In 2001, however, the levels of spraying were extremely low in the villages in which spraying for mirids occurred and were zero in other sample villages. By 2004, the largest increase in the use of insecticide for mirids control is recorded, rising in nearly all sample villages. Indeed, the importance of understanding the linkage between the expansion of *Bt* cotton area and the emergence of mirids is seen by noting the big amount of rise in the level of insecticide used to control for all secondary insects is from the increase in the level of insecticide use to control mirids.

However, when we examine the trend of insecticide use for mirids after 2004, the rising trend was not occurred in many villages in our samples. Between 2004 and 2006 insecticide use on mirids fell on the *Bt* cotton-producing plots in Hebei, Shandong, and Henan-Taikang (rows 2, 3, and 4). Hence, to conclude on the basis of the descriptive data there is a linkage between *Bt* cotton adoption and the emergence of secondary insects (focus on mirids) appears to be premature.

The descriptive statistics in Table 2 seem to suggest that the increased or decrease use of insecticides to control for mirids is not fully consistent with the trend of *Bt* cotton area expansion. But this pattern of insecticide use on mirids seems consistent with previous findings. Wu *et al.* (2002) suggested that there also is a connection between mirid infestations and rainfall (the more the rainfall the higher the probability of an outbreak) and between mirid infestations and the tem-

Table 2 Total insecticide use (kg ha^{-1}) to control for bollworms and secondary insects on plots cultivated by farmers producing *Bt* cotton in China, 2000-2006[1)]

Location of villages (province-county)		Insecticide use to control for bollworm				Insecticide use to control for all secondary insects[2)]				Insecticide use to control for mirids			
		2000 (1)	2001 (2)	2004 (3)	2006 (4)	2000 (5)	2001 (6)	2004 (7)	2006 (8)	2000 (9)	2001 (10)	2004 (11)	2006 (12)
Average	(1)	13.8	8.5	3.8	8.3	6.5	15.6	19.6	16.7	0.0	0.3	7.1	5.9
Hebei-Xinji	(2)	14.7	9.8	2.9	19.4	6.8	7.0	27.7	16.9	0.0	0.0	15.5	10.3
Shandong-Liangshan	(3)	14.5	8.2	3.2	5.3	6.4	10.8	7.6	5.8	0.0	0.0	3.7	2.6
Henan-Taikang	(4)	16.8	3.3	4.6	5.8	7.2	10.0	23.0	14.1	0.0	1.0	11.4	6.4
Henan-Fugou	(5)	6.3	4.4	3.3	7.8	5.3	9.4	15.9	16.9	0.0	0.6	4.6	8.4
Anhui-Dongzhi	(6)	-	8.5	3.5	3.8	-	38.0	25.0	23.7	-	0.3	0.1	4.0
Anhui-Wangjiang	(7)	-	17.5	8.2	8.0	-	27.5	22.3	22.5	-	0.5	0.1	5.7

[1)] Authors' surveys.

[2)] Insecticide use to control for secondary insects includes all insecticides that were used to spray for any non-bollworm infestation, including insecticide use to control for mirids.

perature (the lower the temperature, the higher the probability of an outbreak in a certain interval). Hence, an alternative hypothesis that is the rise of mirid infestation and the need to use insecticides to control for them has nothing to do with the expansion of *Bt* cotton, but is due primarily to the climatic factors.

REGRESSION ANALYSIS METHODOLOGY

Because the descriptive analysis is inconclusive, and due to the fact that conceptually it is possible (indeed probable) that other factors might affect insecticide use for controlling mirids (in addition to *Bt* cotton area and the amount of insecticide used to control bollworms, which is affected by the intensity of adoption of *Bt* cotton), multiple regression analysis is needed. To implement a test that can isolate the effect of bollworm control on mirids insecticide use, a general insecticide use model at the farm level (Huang *et al*. 2003; Pingali *et al*. 1994; Qaim and Zilberman 2003) is used as a starting point for the analysis. To this basic framework, however, two modifications are made: First, the model is estimated for insecticides used for mirids (that is, the left hand side dependent variable is volume of insecticide used to control for mirids); and second, a measure of the level of insecticide used to control bollworms is added as an explanatory variable:

$$\text{Insecticide use to control for mirids} = f\,(\text{Insecticide use to control for bollworms; Climate factors; Others factors}) \qquad (1)$$

Where "Insecticide use to control for mirids" (henceforth, *Qmirids*) is the quantity of insecticide used to control for mirids in kilogram per hectare; "Insecticide use to control for bollworms" (*Qbollworm*) is the quantity of insecticide use to control for bollworms; "Climate factors" are the rainfall and the temperature in *Bt* cotton growing season; and "Other factors" are defined as below. The attractiveness of equation (1) is that it allows for the estimation of the net impact of the use of insecticide for controlling bollworms on the level of insecticide used for controlling mirids. Hence, if the rise of *Bt* cotton not only allows farmers to reduce their use of insecticide for the control of bollworms but also leads to the rise of mirids because the *Bt* toxin's narrower toxicity range encourages the rise of mirids infestations, the coefficient on the *Qbollworm* variable should be negative. If there is an effect (that is, if the coefficient is negative and significantly different from zero in a statistical sense), the magnitude of the coefficient can also be combined with information about the changing quantities of insecticide use to estimate the size of the mirids effect.

Taking advantage of the dataset (both its time dimension and the fact that information on production is available at the plot-level), the empirical version of the model in equation (1) that is to be estimated is:

$$Qmirids = a + c \times Qbollworm + g \times Hybrid + h \times miridPrice + l \times FarmSize + q \times Training + r \times Household\ dummies + \sum_{i=5}^{9} d_i \times Temperature_i + \sum_{i=5}^{9} f_i \times Rainfall_i + u \qquad (2)$$

In other words, equation (2) estimates the effect of the variables on the right hand side of the equation on *Qmirids*. The main variable of interest is *Qbollworm* which is the quantity (in kilograms per hectare) of the chemical insecticide used to control bollworms, and 10 climate variables (rainfall in May, June, July, August, and September; average daily maximum temperature in May, June, July, August, and September).

As noted above, however, to explain the net effect of *Qbollworm* and "Climate factors" on *Qmirids*, other factors that influence insecticide use on the plots of farmers need to be control for. In order to control for the unobservable factors that could be affecting the results, we include a set of all household dummy variables in the model (henceforth, the household fixed-effects model). Specified this way, we are able to purge all household constant unobservable factors over time (e.g., Farmers' insecticide use habit, which was not controlled in previous research). Except for these variables, four other variables (or sets of variables) are included. The first is Hybrid seed dummy variable (*Hybrid*, the variable equals one if it is hybrid cotton, zero otherwise). The second is the price of insecticides for mirids (*miridPrice* measured as yuan per kilogram). The third is the size (hectare) of the household's total area of cultivated land (or *FarmSize*). The human capital of the farmer is included and is measured as the household *Training* (measured as a dummy variable, where one equals the case in which the household has attended at some time in the past a course focused on training in insect management; and zero otherwise).

It also is possible that estimates of *c* the parameter of interest (the coefficient measuring the net effect of *Qbollworm* on *Qmirids*), could be subject to endogeneity bias (due to simultaneity or unobserved heterogeneity). To eliminate this possible source of bias, an instrumental variable (IV) approach has been used in a two-stage least squares estimating framework (2SLS). The price of insecticides for bollworms was used as IV in this study. Since the price of insecticides for bollworms only affects *Qbollworm* and should have no independent effect on *Qmirids*, predicted values of *Qbollworm* are then used in place of *Qbollworm* in the estimation of equation (2). If *Bollwormprice* (the price of insecticides for bollworms) meets the criteria of an IV (which can be shown to be so in a statistical sense), the coefficient on the predicted *Qbollworm* variable in equation (2) provides a consistent estimate of the effect of *Qbollworm* on *Qmirids*.

Equation (2) was estimated using a subset of data discussed in Table 1. We exclude data in 1999 and 2000 in the regression because there is no data available for insecticide uses for mirids. Therefore we have to limit our econometric analyses to CCAP's recent three rounds of surveys in 2001, 2004 and 2006. We also exclude non-*Bt* cotton because there were very few households that planted non-*Bt* cotton in our samples after 2001. At end, there are 1 821 observations (*Bt* cotton production plots) from 422 households. A statistical summary of all variables used in the regression is provided in Appendix Table.

RESULTS AND DISCUSSION

The results of the multiple regression estimation of equation (2) demonstrate that the model performs well generally and that there is little support for the hypothesis that the expansion of *Bt* cotton sown area (and concomitant fall in the use of insecticide for bollworms) has led to an emergence of mirids (Table 3). The performance of the model can be evaluated by how well the coefficients on some of the control variables conform with a priori expectations. In fact, the signs on the profitability variable (*miridPrice*) is as expected. When the price of insecticide for mirids rises, insecticide use for mirids falls.

More importantly, regardless of the choice of estimator (two are used, OLS and 2SLS), the coefficient on the *Qbollworm* variable is insignificant (Table 3, row 1). In other words, the findings of the analysis suggest that the level of insecticide use to control for mirids is not related to the level of insecticide use to control for

Table 3 Results of regression analysis of determinants of insecticide use to control for mirids on *Bt* cotton plots cultivated by cotton-producing farmers in China, 2001-2006

Parameter	Insecticide use to control mirids (kg ha^{-1})	
	Model I	Model II (2SLS)
Insecticide use to control for bollworm	0.013	-0.025
(*Qbollworm*)	(0.56)	(0.38)
Insecticides price for mirids	-0.029	-0.030
	(2.81)***	(2.92)***
Farm size (ha)	-0.833	-0.828
	(0.91)	(0.91)
Training dummy	-1.049	-1.146
	(1.55)	(1.62)
Hybrid variety dummy	1.156	1.109
	(2.28)**	(2.15)**
Average daily maximum temperature_5	-8.286	-8.340
	(7.33)***	(7.33)***
Average daily maximum temperature_6	-3.853	-3.746
	(6.41)***	(6.01)***
Average daily maximum temperature_7	3.982	3.976
	(3.27)***	(3.26)***
Average daily maximum temperature_8	16.807	16.720
	(5.47)***	(5.44)***
Average daily maximum temperature_9	6.163	6.337
	(2.90)***	(2.98)***
Rainfall_5	-0.135	-0.135
	(8.55)***	(8.47)***
Rainfall_6	-0.012	-0.012
	(2.41)**	(2.37)**
Rainfall_7	-0.035	-0.036
	(6.27)***	(6.21)***
Rainfall_8	0.026	0.025
	(5.58)***	(5.25)***
Rainfall_9	0.236	0.233
	(5.85)***	(5.79)***
Intercept	-483.651	-486.848
	(3.16)***	(3.19)***
421 household dummy variables	Estimated but not reported here	
Observations of plots	1 821	1 821
R squared	0.77	NA

*, ** and *** represent statistically significant at 10, 5, and 1%, respectively. Absolute value of robust *t* statistics in parentheses. In the two-stage least squares model (2SLS), the first stage estimates an equation for the determinants of *Qbollworm* as a function of all of the independent variables in the equation reported in this table plus an instrument which was *insecticides price for bollworms*.

bollworms. If mirids had emerged systematically as the level of insecticides used to control for bollworms fell (which occurs as the area planted to *Bt* cotton increases), the coefficient on *Qbollworm* should have been negative and significant. In addition, its surprising that 10 climate variables are significantly in a statistical sense. The significant coefficient is consistent with the findings of Wu *et al*. (2002) that the rise and fall of mirids is related in some way (in this case perhaps the main way) to climatic events-such as temperature and rainfall.

Further analysis also is needed to measure not only the *direction* of the relationship, but also its *magnitude*. In fact, the decomposition analysis in Table 4 shows that, on average, 73.5 percent of rise in the level of insecticide used to control for mirids from 2001 to 2004 is due to climate factors in *Bt* cotton growing season. In other words, according to the analysis, at least there are two findings. Firstly, climate is key factor resulted in rise in the level of insecticide used to control for mirids from 2001 to 2004. Secondly, the reduced use of insecticide controlled for bollworms is not a major reason that has led to increase in the level of insecticide use to control for mirids from 2001 to 2004.

Although after ten years of the commercialization of *Bt* cotton there is little evidence of the emergence of a secondary pest (focus on mirids) population that does not mean that in the future it will not happen in the case of cotton or some other genetically modified crop (e.g., rice) that is being tested currently. One lesson from the current study and the review of the entomology literature is that insect population dynamics are complex and that farmer practices, whether through spraying or adoption of *Bt* crops, affects the ecology in which pests (both good and bad) live and breed. Because of this, as genetically crops expand their area, it is important to maintain active programs of integrated pest management in order to try to mitigate any adverse effects.

It also should be noted that while the discussion in the paper has been focused on the potential adverse effects of the expansion of *Bt* cotton, it is also equally plausible that the rapid adoption of *Bt* cotton also has had positive effects on the bio-diversity of cotton-producing regions. For example, Wu and Guo (2005) shows that the narrow toxicity of *Bt* cotton and the reduction of conventional insecticides also allows more beneficial insects to survive.

Table 4 Result of decomposition analysis: percentage of change in insecticide use to control for mirids that is due to changes in temperature and rainfall, 2001 to 2004, based on the coefficient in Table 3 Model II

Year	A	B	C	D=B+C	E=D/A × 100 (%)
	Chang in the amount of actual insecticide use (kg ha^{-1})	Chang in the amount of insecticide use due to temperature in cotton growing season (kg ha^{-1})	Chang in the amount of insecticide use due to rainfall in cotton growing season (kg ha^{-1})	Chang in the amount of insecticide use due to weather in cotton growing season (kg ha^{-1})	
2001-2004	6.8	0.6	4.4	5.0	73.5

Appendix Table A statistics summary of variables used in regression

Variable	Units	Mean	Std. Dev.
Insecticide use to control for bollworm (*Qbollworm*)	kg ha^{-1}	7.31	10.24
Insecticide price for bollworm	RMB yuan kg^{-1}	27.03	14.80
Insecticide use to control for mirids (*Qmirids*)	kg ha^{-1}	5.17	7.51
Insecticides price for mirids	RMB yuan kg^{-1}	25.96	16.29
Hybrid variety dummy (1=Yes; 0=No)		0.30	0.46
Farm size	ha/household	0.77	0.42
Training dummy (1=Yes; 0=No)		0.32	0.47
Average daily maximum temperature_5	°C	27.09	1.11
Average daily maximum temperature_6	°C	31.78	1.60
Average daily maximum temperature_7	°C	31.82	1.02
Average daily maximum temperature_8	°C	30.50	1.11
Average daily maximum temperature_9	°C	27.22	0.90
Rainfall_5	mm	68.33	51.90
Rainfall_6	mm	108.12	63.16
Rainfall_7	mm	194.06	132.89
Rainfall_8	mm	132.94	73.95
Rainfall_9	mm	36.61	30.69

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References

Bates S L, Zhao J Z, Roush R T, Shelton A M. 2005. Insect resistance management in GM crops: past, present and future. *Nature Biotechnology*, **23**, 57-62.

Bennett R M, Ismael Y, Kambhampati U, Morse S. 2004. Economic impact of genetically modified cotton in India. *AgBioForum*, **7**, 96-100.

Chu H F. 1960. Trends and forcast for occurrence of cotton insects. *Entomological Knowledge*, **6**, 57-62. (in Chinese)

Chu H F, Meng H L. 1958. Studies on three species of cotton plantbugs, *Adelphocoris taeniophorus* Reuter, *A. lineolatus* (Goeze), and *Lygus lucorum* Meyer-Dür (Hemiptera: Miridae). *Acta Entomologica Sinica*, **8**, 97-118. (in Chinese)

Huang J K, Hu R F, Rozelle S, Qiao F B, Pray C. 2002a. Transgenic varieties and productivity of smallholder cotton farmers in China. *Australian Journal of Agricultural and Resource Economics*, **46**, 367-387.

Huang J K, Rozelle S, Pray C, Wang Q F. 2002b. Plant biotechnology in China. *Science*, **295**, 674-677.

Huang J K, Hu R F, Pray C, Qiao F B, Rozelle S. 2003. Biotechnology as an alternative to chemical insecticides: a case study of Bt cotton in China. *Agricultural Economics*, **29**, 55-67.

Ismael Y, Thirtle C, Beyers L, Bennett R, Morse S, Kirsten J, Gouse M, Lin L, Piesse J. 2001. *Smallholder Adoption and Economic Impacts of Bt Cotton in the Makhathini Flats, Republic of South Africa* (Report for DFID Project R7946). Natural Resources Policy Research Programme, London, U.K.

Men X Y, Ge F, Edwards C A, Yardim E N. 2005. The influence of pesticide application on *Helicoverpa armigera* Hübner and sucking pests in transgenic *Bt* cotton and non-transgenic cotton in China. *Crop Protection*, **24**, 319-324.

Perlak F J, Oppenhuizen M, Gustafson K, Voth R, Sivasupramanian S, Heering D, Carey B, Ihrig R A, Roberts J K. 2001. Development and commercial use of Bollgard® cotton in the USA – Early promises versus today's reality. *The Plant Journal*, **27**, 489-502.

Pingali P L, Marquez C B, Palis F G. 1994. Pesticides and Philippine rice farmer health: a medical and economic analysis. *American Journal of Agricultural Economics*, **76**, 587-592.

Pray C, Ma D M, Huang J K, Qiao F B. 2001. Impact of Bt cotton in China. *World Development*, **29**, 813-825.

Pray C, Huang J K, Hu R F, Rozelle S. 2002. Five years of Bt cotton in China – The benefits continue. *The Plant Journal*, **31**, 423-430.

Qaim M, Zilberman D. 2003. Yield effects of genetically modified crops in developing countries. *Science*, **299**, 900-902.

Ting Y Q. 1957. Studies on and control of cotton mirids in Shaanxi, China. *Acta Universitatis Agriculturalis Boreali Occidentalis*, **4**, 37-76. (in Chinese)

Ting Y Q. 1964. Studies on the population fluctuations of cotton mirids in the cotton cultivation region of Kwanchung, Shensi, China. *Acta Entomologica Sinica*, **13**, 298-310. (in Chinese)

Traxler G, Godoy-Avila S, Falck-Zepeda J, Espinoza-Arellano J J. 2001. *Transgenic Cotton in Mexico: Economic and Environmental Impacts* (unpublished report). Department of Agricultural Economics, Auburn University, Auburn, AL.

Wu K M, Li W D, Feng H Q, Guo Y Y. 2002. Seasonal abundance of the mirids, *Lygus lucorum* and *Adelphocoris* spp. (Hemiptera: Miridae) on Bt cotton in northern China. *Crop Protection*, **21**, 997-1002.

Wu K M, Guo Y Y. 2005. The evolution of cotton pest management practices in China. *Annual Review Entomology*, **50**, 31-52.

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