Bt-cotton and secondary pests

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Abstract: Bt-cotton seed has been effective to control the damage of bollworm in Chinese cotton production since 1999, reducing the need for pesticides and increasing incomes of Chinese farmers. Field data collected in 2004 indicates that these benefits have been eroded by increasing the use of pesticides aimed to control secondary pests. The combination of Bt-cotton seed and other forms of biological pest control may help farmers regain the economic and environmental benefits of previous years. Failure to find a solution, may lead to the discontinuation of the use of Bt-cotton seed in China and elsewhere.

Keywords: Bt-cotton; China; secondary pests; resistance.

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1 Introduction

The introduction of genetically modified Bt-cotton seed in several developing countries is a powerful illustration of the benefits offered by modern science to increase productivity, reduce rural poverty, improve food security and protect the environment. However, recent developments in China point to the need for careful management of modern technology, such as genetically modified seed, to extract the greatest benefits and avoid unintended negative effects in the long run.

Bt-cotton seeds were developed by the Chinese Academy of Agricultural Sciences and Monsanto to resist leaf eating bollworms in China – a major pest in cotton crops, the control of which requires heavy use of chemical pesticides. Bt-cotton is an efficient in reducing bollworm infestation. Chinese farmers who switched to Bt-cotton, reduced the number of sprayings from about 20 to 6 or 7, each growing season and the amount of pesticide was reduced by 50–80% in the first couple of years after adoption (Huang et al., 2002a, 2003; Pray et al., 2002). The planting of Bt-cotton also resulted in large a reductions in pesticide use in other countries, for example, 39% in India (Qaim and Zilberman, 2003), 47% in Argentina (Qaim and deJanvry, 2003), 77% in Mexico (Traxler et al., 2003) and 58% in South Africa (Boggess et al., 1985). Meanwhile, cotton yields per hectare remained constant or increased in all countries (Huang et al., 2002a, 2002b; Qaim and Zilberman, 2003). Savings on pesticide use and higher yields resulted in higher incomes of farmers and reduced health risks (Huang et al., 2002a,b, 2003; Pray et al., 2002; Qaim and Zilberman, 2003).

Many have suggested that an effectiveness of Bt technology could not be sustained unless properly managed. If used indiscriminately, the potential exists for the buildup of resistance to Bt-cotton, requiring increased spraying to reduce pest damage. Little evidence exists of such a buildup of resistance among bollworm. This paper presents evidence of a related problem eroding the profits of Bt-cotton farmers in China. Specifically, we find that those using Bt-cotton have increased their pesticide use substantially, eliminating all monetary benefits of using the genetically engineered seed.

The increasing uses of pesticide are reportedly targeted at secondary pests, which were of minor or sporadic importance prior to the adoption of Bt-cotton. Prior to the use of Bt-cotton, these secondary pests were controlled by the heavy use of broad spectrum pesticide which, although aimed at bollworm, also controlled secondary pests. It can take several years for secondary pest populations to proliferate to a point where they require some effort or intervention to avoid crop losses. This phenomenon suggests the need for farmer education regarding pest management and best practices when using Bt-technology or other genetically modified crops.

2 Adoption of Bt-cotton in China

In 1997, Chinese cotton farmers were first given access to Bt-cotton. Annual farm surveys in the major cotton, producing provinces during the period 1999–2001 (Wang et al., 2006) showed that net incomes to farmers planting Bt-cotton was 7% higher than net incomes to farmers planting conventional cotton in 1999, increasing to 36% in 2000 and 10% in 2001 (Pray et al., 2002). Rapid adoption by farmers resulted. Thus, the area planted with Bt-cotton in China increased from 34,000 ha or 0.7% of the total Chinese cotton area, in 1997 to 3.7 million ha, or 65% of the total cotton area, in 2004 (Huang et al., 2002a; 2005).More than 5 million farmers, with an average cotton area of 0.75 ha each, planted Bt-cotton in 2004 (Huang, 2005).

Much of the research since its introduction has been focused on the need for refuge and whether resistance to Bt technology has built up in bollworm populations (see e.g. Huang et al., 2002b). Alternatively, we focus on the possibility of secondary pest infestations. The risk of an increasing concentration of, and damage from, secondary pests associated with the application of chemical pesticides toxic to only the primary pest is widely recognised in agricultural sciences (Harper and Zilberman, 1989; Hueth and Regev, 1994; Hueth et al., 1992; Wu and Guo, 2005; Wu et al., 2002). It should therefore not be a surprise that the substitution of broad spectrum chemical pesticides, with a narrow spectrum toxin such as Bt, would result in a higher concentration of secondary pests. Field experiments in China comparing Bt-cotton without pesticides with conventional cotton with pesticides designed to control bollworm infestations found a significantly higher concentration of secondary pests in the Bt-cotton fields (Wu and Guo, 2005; Wu et al., 2002). The researchers conclude that secondary pests would be a significant threat to Bt-cotton unless preventive action is taken – a conclusion born out by our analysis. Such build up of secondary pests could happen slowly – developing over a period of years. Hence, early studies could fail to notice any impact of secondary pest infestations.

3 Data and methods

In China, data on the production of cotton are not available from government or industry. Therefore, we conducted a household survey in November 2004, seven years after Bt-cotton was initially commercialised in China. This research was jointly conducted by the Center for Chinese Agricultural Policy, Beijing (CCAP) of Chinese Academy of Science (CAS) and Department of Applied Economics and Management at Cornell University. Our research team travelled to 5 provinces: Hebei, Shangdong Henan, Anhui and Hubei, all of which are major cotton-producing areas in China. The survey was administered to 481 households and each farmer in our sample was interviewed for about 2 hr in order to collect detailed information on cotton production and investment in various inputs and pesticides. The sample was a stratified random sample. We selected the provinces and counties carefully so that we could compare the performances of Bt and conventional cotton under similar production conditions. After county selection, we randomly selected the villages and farmers proportionally within the villages. The final sample comes from 20 villages in 10 counties of 5 provinces. CCAP conducted similar surveys (using identical procedures) in 1999, 2000 and 2001. Previous surveys included 283 farmers in 1999, 407 in 2000 and 366 in 2001. The unique panel dataset from 1999 to 2004 enable us to analyse the performance of Bt adoption over time. Table 1 presents summary statistics for farm size, yield average expenditure on various production inputs between Bt and non-Bt farmers. In this analysis, we use only data covering certified and sanctioned Bt seed technology, excluding both illegal seeds and seed saved from previous years crop.

Table 1 Summary statistics for important input and output variables between Bt and non-Bt farmer in 2004

	Non-Bt	*Bt*
Farm size (ha)	0.63	0.54
Yield (kg/ha)	2475	2625
Price of cotton ($/kg)	0.6	0.61
Fertiliser ($/ha)	329.94	302.16
Irrigation ($/ha)	39.79	78.02
Labour hour (day/ha)	360	386.85

We analyse the data using Stochastic Dominance (SD) tests. SD tests are a powerful tool to provide rankings of two distributions. It examines whether one distribution has unambiguously more or less advantage over another. The theory of SD (Hadar and Russell 1969; Hanoch and Levy, 1969; Rothschild and Stiglitz, 1970; Whitmore, 1970) gives a systematic framework for analysing the economics rankings of different distributions. SD has seen considerable theoretical development and empirical application in the last decades, in various areas of economics (see e.g. Levy, 1992; Levy, 1998) though it is primarily applied in the fields of decision under risk. It is useful both for positive analysis (where the objective is to analyse the decision rules actually used by decision makers) as well as in normative analysis (where the objective is to support practical decision making).

Suppose, we have two distributions with Cumulative Density Functions (CDF) given by $F(x)$ and $G(x)$, respectively. Then CDF $F(x)$ first-order stochastically dominates $G(x)$ if and only if, for all monotone non-decreasing functions $u(x)$:

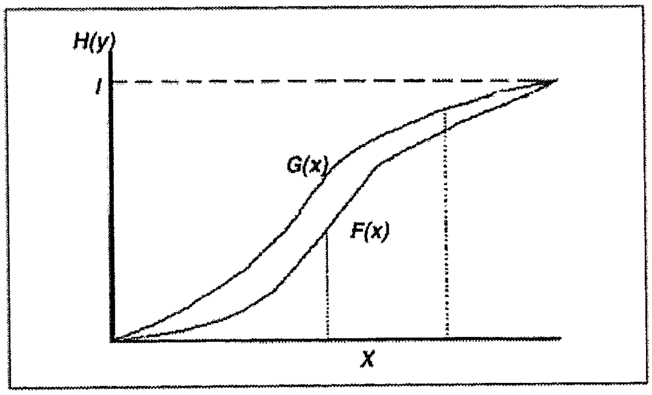
$$\int_{\infty}^{\infty} u(x)\mathrm{d}F(x) \geq \int_{\infty}^{\infty} u(x)\,\mathrm{d}G(x)$$

Thus, the expected value of u is at least as large under distribution F as it is in distribution G, as long as the valuation function is such that more is better. In this sense distribution F stochastically dominates distribution G. It has been shown that an equivalent way of expressing this is to say that for all x,

$$G(x) \geq F(x)$$

Thus, if the CDF of distribution G is always at least as large as that of distribution F, (i.e. distribution G always has more mass in the lower part of the distribution) then F first-order stochastically dominates G. Figure 1 shows an example of how the CDFs of G and F may look.

Figure 1 An example of a SD test



SD has been a useful notion in examining decisions between lotteries where x represents the monetary rewards possible under each gamble. Clearly, one should prefer a gamble that first-order stochastically dominates all others. This analysis has been primarily used to examine profits. In this paper, we will use the notion of SD to examine revenues, pesticide use and pesticide expenditure. This requires some explanation.

Given that the surveys were designed to represent similar distributions of farms growing Bt or non-Bt-cotton, respectively, our SD tests represent the impact of Bt use on the distribution of the underlying variable. Thus, if expenditure on pesticides under one technology first-order stochastically dominates that of a second technology, all else being equal, we can say that an individual should prefer the second technology (as it will require less expenditure). This will hold only if the cost of the two technologies is equal and if revenue under the two technologies is equal. In our case, the cost of Bt seed is regulated and reasonably high. This in addition to analysis of the revenue under both technologies allows us to draw strong conclusions regarding the performance of Bt technology in China in 2004.

4 The onset of secondary pests

Our analysis shows no economic advantage for farmers planting Bt-cotton compared with those who planted conventional cotton seeds. In fact, Bt-cotton farmers were slightly worse off. Net revenue is defined as the value of the cotton sold, minus expenditures on variable inputs. Figure 2 shows the CDF of net revenue for non-Bt-cotton farmers stochastically dominates that of Bt-cotton farmers. The average net revenue was 8% lower for farmers who grew Bt-cotton than for farmers growing conventional cotton. Given the proven effectiveness of Bt-cotton in fighting bollworm, this poor performance may seem somewhat of a puzzle. Our survey suggests the main reason for the eroding advantage of Bt-cotton was the increasing prevalence of secondary pests for which Bt was never designed to control and the higher cost of Bt-cotton seeds.

As given in Table 2, Bt-cotton farmers increased the number of sprays per season from less than 7 in 1999 to 18 in 2004, while the number of sprays applied to conventional cotton showed no particular time trend. The increasing number of sprays were reported to be targeted at secondary pests, which were of minor or sporadic importance prior to the adoption of Bt-cotton because they were controlled by the heavy use of broad spectrum pesticide which, although aimed at bollworm, also controlled secondary pests.

Figure 2 First-order SD test of net revenue (US $/ha) of Bt and non-Bt farmers in 2004

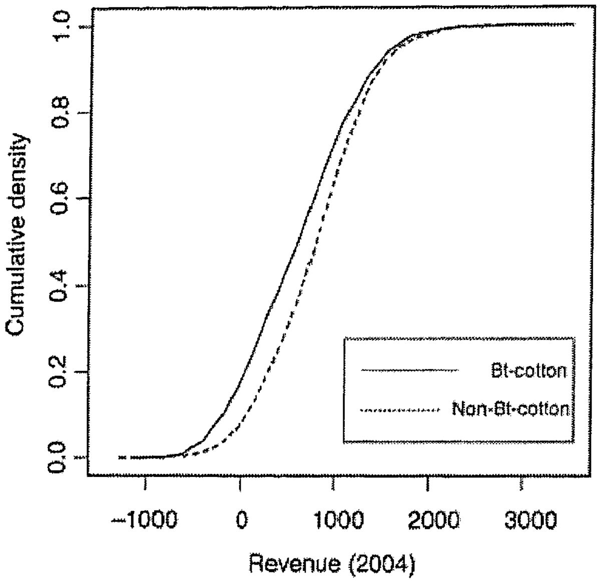


Table 2 Number of pesticide sprays per season between Bt and non-Bt during 1999–2004

	1999	*2000*	*2001*	*2004*
Bt farmers	6.6	9.3	13.7	18.23
Non-Bt farmers	20	21.1	28.3	22

It may take several years for secondary pests to proliferate to a point where they require some effort or intervention to avoid crop losses. Thus, previously published studies of Bt-cotton in its early years' adoption may not provide evidence of growing secondary pests. Table 3 presents the findings from the farm surveys conducted in 2001 and 2004. The quantity of pesticide used to control secondary pests increased several fold in the 4 provinces for which we have data for the two years. As shown in Figure 3, the pesticide used to control secondary pests in 2004 dominates that for 2001 at all levels of use, thus suggesting that pesticide expenditures due to secondary pests has increased the cost of cotton production. As expected, pesticide expenditures to control bollworm were much lower in Bt-cotton crops in Figure 4, but total expenditures on pesticides for bollworm and secondary pests were virtually the same for Bt-cotton crops and other cotton crops in Figure 5. The large economic gains experienced by adopters of Bt-cotton seed in 1999–2001 evaporated by 2004 largely due to the rapid increase in the pressure from secondary pests.

Table 3 The average quantity (kg/ha) of pesticides used by farmers growing Bt-cotton to control secondary pests in each province for 2001 and 2004

	2001	*2004*
Hebei	0.1	15.6
Henan	1.3	8.1
Shangdong	0.1	3.9
Anhui	5.1	8.7

Figure 3 First-order SD test of amount of pesticides (kg/ha) used on secondary pests for Bt farmers in years 2001 and 2004

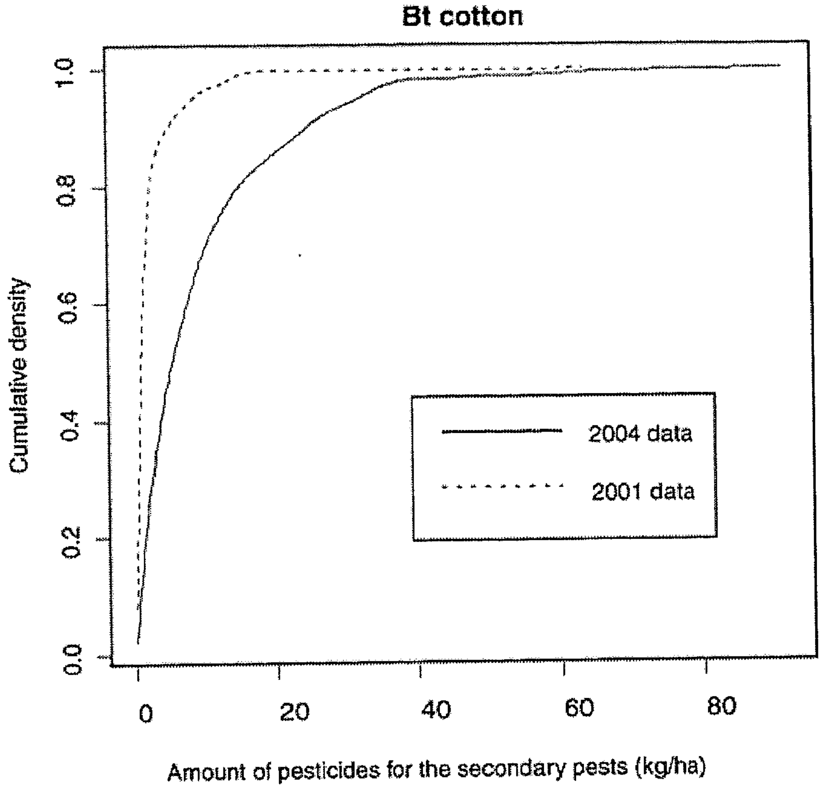


Figure 4 First-order SD test of pesticide expenditure ($/ha) on primary pest bollworm for Bt and non-Bt in 2004

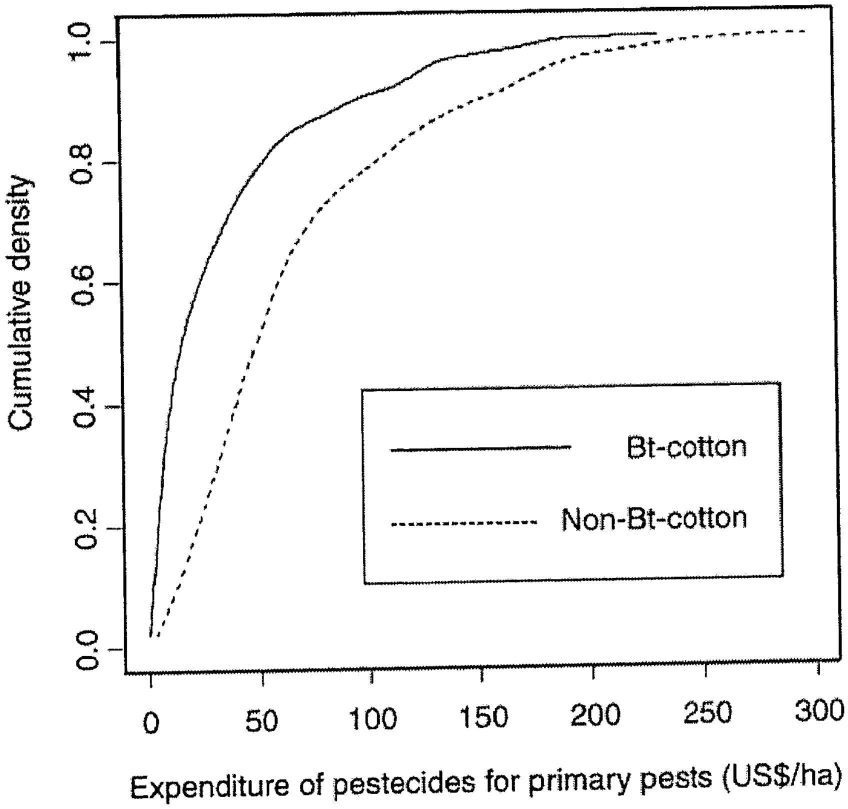
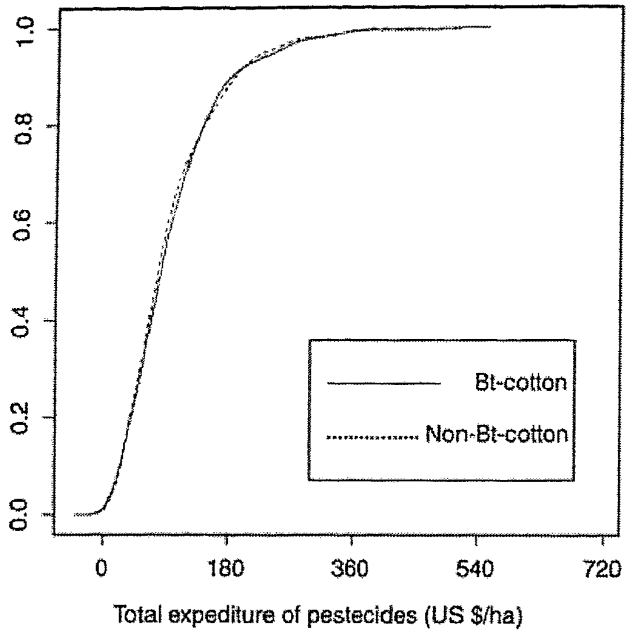


Figure 5 First-order SD test of pesticide expenditure (US$/ha) between Bt and non-Bt farmers in 2004



5 Conclusions

The findings reported here provide clear evidence that Chinese farmers – in the villages surveyed – who planted Bt-cotton in 2004 made less money than the farmers who planted conventional cotton. Furthermore, the findings from this analysis indicate that the economic benefits associated with the use of Bt-cotton are threatened by the failure to consider the risks of increasing damage from secondary pests or higher costs of pesticides to control them. In order to recapture the economic benefits from Bt-cotton in China and to prevent losses to secondary pests in Bt-cotton fields in other countries, research is urgently needed to develop and test solutions. Although this analysis was not designed to provide such solutions, options to consider might include the application of integrated pest management in Bt-cotton fields, including the introduction of natural predators of the secondary pests, the enforcement of refuge areas in which broad spectrum pesticides are used as well as attempts to develop cotton seed with multiple toxins that would be resistant to bollworms as well as the most important secondary pests. Failure to develop an economically viable solution to the secondary pest problem is likely to result in a discontinuation of the use of Bt-cotton in China and possibly elsewhere. Farmers will continue to plant Bt-cotton seed only if it is in their economic interest to do so.

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