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Bt cotton and sustainability of pesticide reductions in India

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ABSTRACT

Studies from different countries show that transgenic *Bacillus thuringiensis* (Bt) crops can reduce chemical pesticide use with positive economic, environmental, and health effects. However, most of these studies build on cross-section survey data, so that longer term effects have not been analyzed. Bt resistance and secondary pest outbreaks may potentially reduce or eliminate the benefits over time, especially in developing countries where refuge strategies are often not implemented. Here, we use data from a unique panel survey of cotton farmers conducted in India between 2002 and 2008. Accounting for possible selection bias, we show that the Bt pesticide reducing effect has been sustainable. In spite of an increase in pesticide sprays against secondary pests, total pesticide use has decreased significantly over time. Bt has also reduced pesticide applications by non-Bt farmers. These results mitigate the concern that Bt technology would soon become obsolete in small farmer environments. The survey data on actual pesticide use in farmers' fields complement previous entomological research.

1. Introduction

Transgenic crops that contain Cry genes from *Bacillus thuringiensis* (Bt) were commercialized in many countries and widely adopted by farmers over the last 15 years. Several studies showed that Bt crops, which provide resistance to some lepidopteran and coleopteran insect pest species, have helped reduce chemical pesticide use and increase effective yield (Huang et al., 2005; Qaim and de Janvry, 2005; Morse et al., 2006; Wossink and Denaux, 2006; Krishna and Qaim, 2007; Subramanian and Qaim, 2009; Carpenter, 2010). Next to Bt maize, Bt cotton is currently the most widely grown Bt crop (James, 2010). The largest Bt cotton areas are found in India and China, where the technology is mainly used to control the American bollworm (*Helicoverpa armigera*) and to a lesser extent, spotted bollworm (*Earias vittella*), pink bollworm (*Pectinophora gossypiella*), and related species (Qaim, 2009). In both countries, the cotton sector is heavily dominated by smallholder farmers with land areas of less than 5 ha, who benefit from Bt technology adoption in terms of higher incomes and lower occupational health hazards associated with pesticide sprays (Huang et al., 2002; Hossain et al., 2004; Qaim et al., 2009; Kouser and Qaim, 2011). In India and Pakistan, it was also shown that Bt cotton contributes to poverty reduction and broader rural development (Subramanian and Qaim, 2010; Ali and Abdulai, 2010).

However, there is still uncertainty with respect to the sustainability of these effects. In particular, there are two factors that could undermine the effectiveness of Bt technology over time. First, there could be Bt resistance development in target pest populations (Bates et al., 2005; Tabashnik et al., 2009; Addison, 2010). Second, while primary pests are controlled through Bt, the lower use of chemical pesticides may entail the outbreak of secondary pests, especially mirids, mealybugs, and other sucking pest species, which are not controlled through Bt (Nagrare et al., 2009; Lu et al., 2010). Both factors could potentially lead to chemical pesticide use increasing again after a certain time of reduction. The probability of this happening may be higher in the small farm sector of developing countries, where implementation of Bt refuge strategies and careful monitoring are more difficult. However, beyond such undesirable effects, there are also possible positive spill-overs: widespread use of Bt technology may suppress bollworm infestation levels regionally, such that non-Bt adopters may also be able to reduce their pesticide applications (Carrière et al., 2003; Wu et al., 2008; Hutchinson et al., 2010).

Such aspects were analyzed in the recent literature, mostly through long-term field observations of pest populations in different environments (Carrière et al., 2003; Bates et al., 2005; Marvier et al., 2007; Wu et al., 2008; Tabashnik et al., 2009; Nagrare et al., 2009; Lu et al., 2010). While this is very important to understand ecological interactions, there is hardly any research that has analyzed what this actually means for farmers' pesticide use over time. One exception is China, where farm survey data collected over

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several years were used to analyze pesticide use trends in cotton (Wang et al., 2008, 2009). However, those surveys were not constructed as a panel, which is a drawback when the focus is on evaluating technological impact dynamics.

The objective of the present article is to contribute to this literature with more comprehensive data and analyze whether the pesticide reducing effect of Bt technology is sustainable. The empirical analysis builds on a unique panel survey of cotton growers in India. India is a particularly interesting example, because the country is currently the biggest producer of Bt cotton, and the crop is mostly produced by smallholder farmers. Bollgard I technology, containing the Cry1Ac gene, was officially commercialized in India in 2002. In 2006, Bollgard II technology, containing stacked Cry1Ac and Cry2Ab genes, was also approved. These technologies were developed by Monsanto in cooperation with the Indian seed company Mahyco. By 2010, over six million Indian farmers had adopted Bt cotton on 9.4 million hectares (23.2 million acres) – almost 90% of the country's total cotton area (James, 2010).

2. Materials and methods

2.1. Data

The survey data from cotton farmers in India were collected in four rounds between 2002 and 2008. The sample covers farmers in four different states, namely Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu. These states were sampled purposely to cover a wide variety of different cotton growing situations; they produce 60% of all cotton production in central and southern India (Cotton Association of India, 2008). Central and southern India were also the only regions for which Bt cotton was commercially approved in 2002. Approval for northern India was only given in later years.

In the four states, we randomly selected 10 cotton growing districts and 58 villages, using a combination of census data and agricultural production statistics. Within each village, we randomly selected farm households from complete lists of cotton producers that were provided by the village heads. In total, 341 farmers were sampled in 2002. As the number of Bt adopters was very low in the first year of commercial technology approval, we stratified by adopters and non-adopters and deliberately over-sampled adopters. This was important to have sufficient observations in each group for reliable comparisons within that first year. Thus, technology adoption rates for 2002 are not representative, but the subsamples of Bt adopters and non-adopters are representative for cotton producers in central and southern India (Qaim et al., 2006; Subramanian and Qaim, 2010). Comparison with secondary data on Bt cotton diffusion (James, 2010) shows that adoption rates in our sample almost converged with actual state-wise adoption rates in later years.

The first-round survey interviews took place in early 2003, shortly after the cotton harvest for the 2002 season was completed. It was repeated in 2-year intervals in early 2005 (referring to the 2004 cotton season), early 2007 (referring to the 2006 season), and early 2009 (referring to the 2008 season). To our knowledge, this is the only longer-term panel survey of Bt cotton farmers in a developing country.

To some extent, sample attrition occurred in subsequent rounds, as is normal in panel surveys extending over several years. There are mainly two reasons for the fact that some farmers from the first round could not be included in subsequent rounds. First, several farmers had stopped cotton cultivation during the period, mostly because of focusing on new cash crops. This primarily happened in two districts of Karnataka and Tamil Nadu, where irrigation projects were started and new cash crops promoted. In particular, the establishment of sugar mills in the vicinity provided price incentives for farmers to switch from cotton to sugarcane in the irrigated areas. Second, a few farmers who grew cotton on temporarily leased-in land had migrated to other areas. This occurred especially in one district in Karnataka, where migrant farming is commonplace. There is no significant difference in the proportion of dropouts between Bt adopting and non-adopting farmers. To account for sample attrition, new cotton growers in the same districts were randomly selected, and the overall sample size was slightly increased. Table 1 shows how the sample size and structure developed over time.

Table 1
Number of farms and plots sampled in the four survey rounds.

Year	No. of farmers		Share of Bt adopters		No. of plot observations		
	All	New in a particular round	All	New in a particular round	All	Bt	Non-Bt
2002	341	–	0.39	–	434	133	301
2004	362	58	0.46	0.40	464	165	299
2006	342	71	0.92	0.93	369	315	54
2008	380	63	0.99	0.95	383	375	8

In the four rounds, almost identical questionnaires with only very slight adjustments and updates were administered through face-to-face interviews. These structured questionnaires had been carefully developed and tested in the local context. The interviews were conducted in the different local languages by a small team of enumerators, who were selected, trained, and monitored by the authors. Sample farmers were asked to provide detailed information about the demographic and socioeconomic situation of their households, including income sources, consumption, education, and access to markets and rural services. Moreover, questions on perceptions about pest control and Bt technology were included. Finally, detailed data on production, revenues, and costs for all agricultural enterprises were collected.

For cotton, such details were captured at the plot level, including the quantities and prices of all inputs used. For pesticides, information was also elicited on the timing of each spraying operation and the exact names of the different chemicals used, allowing us to identify the target pest spectrum and the amount of active ingredients (a.i.) applied. Based on these detailed data on production costs (including differential costs of Bt and non-Bt seeds) and sales revenues, we were also able to calculate agricultural profits for the farm as a whole and per acre of cotton. Farmers that grew Bt and non-Bt cotton simultaneously provided details for both options, so that the number of plot observations in our sample is somewhat larger than the number of farmers surveyed (see right-hand part of Table 1). Sample mean values for the variables that are used later in the regression analyses are shown in Table A1 in the Appendix. The mean farm size is about 12 acres, with an average cotton area of 4.5 acres. Details about pesticide use in Bt and non-Bt cotton are presented in the results section below.

2.2. Statistical analysis

We start the statistical analysis by comparing mean values of pesticide use, cotton yield, seed costs, and profits per acre between Bt and non-Bt plots, in order to see whether there are significant differences and how these differences evolved over time. By 2008, most sample farmers had fully adopted Bt technology, so that the number of non-Bt observations became very small (Table 1). Therefore, for the purpose of these mean value comparisons, we club observations from two consecutive rounds, respectively,