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Farmers' knowledge on pest management and pesticide use in Bt cotton production in china

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ABSTRACT

Even though both empirical studies and field evidences show that Bt cotton can significantly reduce pesticide use, Chinese farmers are still spraying excessive pesticide in field production. Based on primary household surveys in the North China Plain, this study shows that farmers' lack of knowledge on pest management and pesticide use is strongly correlated with their excessive pesticide use. According to this study, improving farmers' awareness and knowledge could potentially reduce pesticide use by 10–15%. The paper concludes with policy implications.

1. Introduction

To meet the demand of its 1.3 billion people, China needs to increase the country's output of all agricultural products. From a nation facing widespread shortages of food and fiber, China has raised agricultural production to levels that no one would have dared predict (Huang, Yang, & Rozelle, 2010). The great success of China's agriculture has been achieved primarily by intensifying farming systems and increasing the level of modern inputs, such as chemical fertilizers and pesticides (Ash & Kueh, 1995; Sonntag, Huang, Rozelle, & Skerritt, 2005). Recognizing the importance of pesticides in battling pests and diseases, farmers applied more and more pesticides on their crop production. Since the early 2000s, China has become the world's largest pesticide consumer (Huang, Wang, & Qiu, 2012).

However, chemical pesticide is a two edge sword. While the rising level of pesticide use certainly has helped farmers to reduce crop yield loss, the high, perhaps excessively high, level of pesticide use may have had a number of adverse consequences. Previous studies showed that pesticide use may pose as a serious danger to the soil and water quality of the agro-ecosystem (Rozelle, Huang, & Zhang, 1997; Smil, 1993) and human health (Pingali, Hossein & Gerpacis, 1997; Qiao, Huang, Zhang, & Rozelle, 2012; Rola & Pingali, 1993). The negative indirect effects and social costs in some cases may exceed the private cost of purchasing pesticides (Huang, Qiao, Zhang, & Rozelle, 2000).

To reduce pesticide use, China's plant breeders have produced thousands of plant varieties with host-plant resistance to insects and diseases (Pray, Huang, Hu, & Rozelle, 2002; Stone, 1988, 1993; Zhuang, 2003). Unfortunately, the effectiveness of these host-plant varieties has fallen over time because of the rising resistance of pests (Crook, 1999; Hu, Huang, & Rozelle, 2002;

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Widawsky, Rozelle, Jin, & Huang, 1998). For example, because of the buildup of resistance, the outbreak of the cotton bollworm had caused great loss of cotton production in the North China Plain in the early 1990s (Huang, Hu, Rozelle, Qiao, & Pray, 2002). In response to the increasing pest resistance, the Chinese government commercialized Bt cotton in 1997, only one year later after it was first commercialized in the USA (Wu, Mu, Liang, & Guo, 2005). Empirical studies showed that Bt cotton had significantly reduced the pesticide use in China (Huang, Hu, Pray, Qiao, & Rozelle, 2003; Huang, Hu, et al., 2002; Pray, Ma, Huang, & Qiao, 2001).

Despite the fact that Bt cotton can effectually control pest problems, field observations showed that Chinese farmers still sprayed excessive pesticides in their cotton fields. Previous studies showed that Bt cotton can effectively control 85–90% of the cotton bollworm, the most common pest in cotton fields in China (Wu & Guo, 2005; Wu, Guo, & Gao, 2002). However, both economists and entomologists had shown that cotton farmers continue to spray high amounts of pesticides in their Bt cotton fields (for example, Huang, Rozelle, Pray, & Wang, 2002; Pemsl, Waibel, & Gutierrez, 2005; Yang, Iles, Yan, & Jolliffe, 2005).

There are many factors affecting farmers' pesticide use activities. These factors include farmers' characteristics, environmental factors as well as the level of pest infestation. For example, theoretical analyses showed that farmers' risk preferences play an important role in agricultural production decisions (Feder, 1980; Just & Zilberman, 1983). As smaller-scale producers, Chinese farmers are less tolerant to crop pest infestations, and give high priorities to the use of pesticides in their field production (Huang, Hu, et al., 2002; Pray et al., 2002). Liu and Huang (2013) found that farmers who are more risk averse use greater quantities of pesticides than risk takers. There are also studies that showed that the wide spread of Bt cotton had caused the outbreak of the secondary pest, which led to the increase of pesticide use in Bt cotton fields (such as Lu et al., 2010; Wang, Just, & Pinstrup-Andersen, 2008).

Farmer's knowledge of pest management and control is one of the factors affecting farmers' pesticide use in practice. Different from that in the developed countries, farmers in developing countries have usually not attended any training programs on the appropriate use of new technologies (Fan, 2001; Matteson, Gallagher, & Kenmore, 1993; Pontius, Dilts, & Bartlett, 2002). During the Green Revolution period, it was well acknowledged that the lack of knowledge has caused excessive pesticide use and further caused the "three R" (resistance, resurgence of pests and residue of pesticides) dilemma in many crops throughout the world (Bernard & David, 2001; Yang et al., 2005). Some researchers (for example, Gould, 1998) worried that a similar misfortune may also happen in the current Gene Revolution period.

However, given the importance of farmers' knowledge of pest management and pesticide use, little empirical work has been conducted to examine the impact in China. To the best of our knowledge, the only exception is Yang et al. (2005). Using data collected in Northern China in 2002, they showed that the farmers' poor knowledge led to the high use of pesticide in field production. However, their results were based on descriptive analysis rather than multivariate regression estimations.

This study therefore aims at investigating the conditional relationship between farmers' knowledge and their pesticide use after controlling for the impacts of other factors. Specifically, we attempt to: (1) understand farmers' knowledge of pest management and pesticide use, including those specifically related to Bt technology and those not specifically related to Bt technology; (2) estimate the impact of farmers' knowledge on pesticide use by setting up and running multivariate regression models; and (3) generate policy implications based on the results of this study.

To meet these objectives, the rest of the paper is organized as follows. In the next section, using survey data we document farmers' knowledge of pest management and their pesticide use, and descriptively chart the way that they appear to move together. In Section 3, we set up an econometric model to isolate the impact of farmers' knowledge on pesticide use. Section 4 presents the results of multivariate regression analyses. Estimation results show that farmers' knowledge has a significant negative impact on pesticide use. According to our estimation, farmers' total pesticide use could be reduced by 10–15% should their knowledge be improved. Finally, the last section concludes with policy implications.

While this study has made significant discoveries about the impacts of farmers' knowledge on pesticide use, it nevertheless has its limitation. That is, using a cross section data set, we cannot fully control the impacts of time-invariant variables. In other words, the estimation results of this study might suffer from omitted variable bias. For example, the conscientious hard-working farmers might also be more knowledgeable and spray less pesticide in their fields. In this sense, impact of knowledge could be over-estimated. However, there are also other omitted variables, such as farmer's risk preference, and number of pesticide shops in a village, that may lead to under-estimation of the impact of knowledge. Because the impacts of these two categories of omitted variables work in opposite directions, we expect that the bias due to omitted variables might not be a big issue in this study.

2. Data collection and farmers' pesticide use in Bt cotton fields

2.1. Data

The data used in this study was collected by the Center for Chinese Agricultural Policy (CCAP) of the Chinese Academy of Sciences (CAS) in 2006 and 2007. The surveys covered three provinces, Shandong, Hebei and Henan in the Yellow River Valley, which is the largest cotton producing region in China. This region is also the first region where Bt cotton was released due to the severity of pest infestation (Huang, Hu, et al., 2002). According to the statistics of the National Bureau of Statistics of China (2008), these three provinces are also the second, third and fourth largest cotton production provinces. In each province, two villages from each of two counties were surveyed. Then 20 households were randomly selected in each village. In total, the year 2006 survey covered 240 households, while eight households attrited from the sample due to out-migration, or not planting Bt cotton in the year 2007 survey.

During the surveys, enumerators interviewed farmers, using a survey form designed to collect basic information on household characteristics (such as family size, land endowment, housing). Demographic information, such as gender, age, education, and marital status, of all labors in each household was also included in the questionnaire. For each cotton plot, detailed information about yields and inputs, such as seed (whether the seed is a hybrid, whether the variety is Bt, seed price etc.), irrigation, fertilizer use (both in quantity and cost), and labor use, is recorded. For chemical pesticide use, enumerators first asked the total number of times that farmers sprayed. For each pesticide spray, a few questions about quantity and cost, and target pests of each spray were asked.

A unique part of the year 2007 survey is that there is a new section in the questionnaire to test farmers' knowledge on pest management, Bt technology and pesticide use. The design of the test questions was jointly made by the project staff and plant protection scientists from the Chinese Academy of Agricultural Sciences and the National Agricultural Technology Extension Service Center. Many questions are similar to those reported by Grossrieder, Yang, Lim, Su, and Ritchie (2005). When we designed the test questions, we followed the following rules: 1) the questions should cover key aspects of daily pest management activities, and both questions specifically related to Bt cotton production (hereafter Bt-specific questions) and other general questions that are not specifically related to Bt cotton production (hereafter, other general questions) should be tested; 2) the questions should be easily understood by all farmers; and 3) both the questions which many farmers often know and the questions which only few of them know should be included. At the end, we selected 10 test questions, including five Bt-specific questions and five other general questions. A brief summary of the 10 questions are shown in Appendix Table 1. The final version of these ten questions had been pre-tested several times before the survey was conducted in the fields to make sure that farmers have no problem in understanding them.

Table 1
Pesticide use in 12 sample villages in 2006 and 2007.

	2006			2007		
	Average	Bottom 10%	Top 10%	Average	Bottom 10%	Top 10%
Total pesticide use (kg/ha)						
Average	22.7	13.8	49.1	19.9	8.9	49.4
Hebei province	27.6	8.4	66.0	29.3	9.3	62.0
Ximu	20.0	7.2	40.9	17.4	7.3	31.9
Dongmu	17.5	8.6	37.4	18.3	7.9	42.0
Mazhuang	42.5	24.3	67.5	37.8	21.3	79.2
Dalishi	33.8	9.8	78.5	40.8	14.7	61.8
Henan province	22.1	4.7	55.9	15.6	5.3	30.7
Shizhuang	21.2	4.9	46.3	16.1	5.9	31.1
Heyanzhang	19.6	4.2	40.6	15.3	7.1	28.4
Dujia	23.0	4.9	42.2	18.5	10.0	34.6
Gonghe	27.5	4.9	95.8	11.5	3.6	21.6
Shandong province	19.0	4.0	58.2	14.5	4.9	31.4
Sunzhuang	13.3	4.0	32.0	11.8	6.1	21.8
Liuxianzhuang	10.0	3.1	22.8	7.9	3.7	13.5
Zhangzhai	24.1	5.6	82.8	16.1	7.2	27.5
Qianhuo	29.9	9.7	56.7	20.9	12.0	35.6
Pesticide used to control bollworm (kg/ha)						
Hebei province	13.6	0.8	35.7	17.5	3.1	44.2
Ximu	9.2	1.1	21.6	7.9	2.3	15.4
Dongmu	6.3	0.0	18.6	10.7	3.5	30.0
Mazhuang	24.6	9.8	44.7	22.3	10.0	53.6
Dalishi	16.9	3.5	36.1	26.6	7.9	44.4
Henan province	6.4	0.0	27.5	3.2	0.0	9.9
Shizhuang	6.8	0.0	27	1.7	0.0	5.2
Heyanzhang	4.1	0.0	15.1	2.9	0.1	7.7
Dujia	7.4	0.0	23.9	5.7	0.9	12.7
Gonghe	8.5	0.0	42.1	1.4	0.0	3.6
Shandong province	7.7	0.5	24.4	5.1	1.0	13.7
Sunzhuang	5.9	0.4	20.0	4.1	1.4	10.3
Liuxianzhuang	5.3	1.4	12.8	3.3	1.2	6.9
Zhangzhai	6.1	0.0	14.5	5.0	0.4	13.8
Qianhuo	13.4	1.8	31.1	7.3	1.6	16.3

Source: Authors' survey.

2.2. Farmers' pesticide use in Bt cotton fields

Table 1 summarizes major statistics in our sample households by village. As shown in Table 1, average pesticide use was as high as 22.7 kg/ha in 2006 and 19.9 kg/ha in 2007 (row 1).[1] In fact, early in 1999 CCAP began its first round of Bt cotton household production surveys in the same sample sites. By analyzing this data, Huang, Hu, et al. (2002) showed that the average pesticide use was 60.7 kg/ha in non-Bt cotton fields and 11.8 kg/ha in Bt cotton fields. Compared to the pesticide use in 1999, even though the pesticide use in 2006 and 2007 was still much less than that in non-Bt cotton fields, it was about two times of the pesticide use in Bt cotton fields.

Increase of the pesticide use in Bt cotton fields might be partially explained by two reasons. First, the pesticide price had dropped from 34.5 yuan/kg in 1999 (Huang et al., 2003) to 29.1 yuan/kg in 2006–2007 (Appendix Table 2). Second, pesticide use to control secondary insects (for example, mirids) has increased rapidly in recent years. For example, Wang et al. (2008) and Wang et al. (2009) reported that the reduction of pesticide use might have facilitated the outbreaks of the secondary pest, particularly mirids in Bt cotton fields.

Table 1 also shows that the quantity of pesticide per hectare varied significantly among villages. In 2006, the average amount of pesticide use in Liuxianzhuang is only 10.0 kg/ha (row 14, Table 1), which is 25% less than that in Mazhuang (42.5 kg/ha, row 5). Similarly, farmers in Liuxianzhuang on average sprayed 7.9 kg/ha, while farmers in Dalishi sprayed 40.8 kg/ha in 2007. A similar pattern was presented when we compared the amount of pesticide use against cotton bollworm by village. As shown in Table 1, the average amount of pesticide against cotton bollworm ranged from 4.1 kg/ha to 24.6 kg/ha in 2006 and from 1.4 kg/ha to 26.6 kg/ha in 2007.

More importantly, even in the same village, the amount of pesticide use per hectare also substantially differed among households. Both in 2006 and 2007, the average pesticide use of the top 10% farmers who applied more pesticides per hectare is often more than 3 times as much as that of the bottom 10% farmers in the same village (columns 2 and 3 for 2006, and columns 5 and 6 for 2007, Table 1). As shown in Table 1, the largest difference is in Gonghe village in the Henan province, wherein the ratio of the top 10% to the bottom 10% reaches near 20 in 2006 (95.8 kg/ha vs. 4.9 kg/ha). Similarly, the pesticide use against cotton bollworm also varies significantly among households within the same villages. Our survey shows that some farmers did not spray pesticides at all, while others sprayed a lot of pesticides to control cotton bollworm (bottom part of Table 1). Since the severity of pest infestation can be considered similar in one village, the difference in the amount of pesticide use might be only explained by the characteristics of the households such as their knowledge about pest management and pesticide use, which is examined in the following sections.[2]

2.3. Farmers' knowledge on pest management and their pesticide applications

Detailed information on farmers' knowledge on pest management is provided in Appendix Table 1.[3] The test result is presented in Fig. 1. As shown in Fig. 1, on average, farmers could correctly answer half of these 10 questions (panel A). We also find that farmers' pest management knowledge on “other general questions” is slightly better than their knowledge on Bt-specific questions (panel B and panel C). But the generally low level of farmers' knowledge on pest management, Bt technology and pesticide use implies that there is great room for the improvement farmers' knowledge through better extension and training in China.

Fig. 1 shows that there is a large difference in farmers' knowledge. Some farmers can only answer one question correctly while some can answer most of these questions. Will the farmers who correctly answered more questions spray less pesticides in field production? In the following, we try to explore whether there is any relationship between farmers' knowledge and their pesticide use. That is, do farmers who have more knowledge spray less amount of pesticide in field production?

To show the relationship between farmers' knowledge and their pesticide use, we classified farmers into two groups based on their test scores: “high-knowledge” group and “low-knowledge” group. To do so, we sort all the farmers by the percentage of questions that they correctly answered. The first half who correctly answered more questions is called the “high-knowledge” group while the other half is called the “low-knowledge” group. Since the severity of pest infestation might be significantly different across regions, we then divide the “high-knowledge” group and “low-knowledge” group by county, respectively, and compare the pesticide use by farmers' knowledge group and by county.

Table 2 shows that there is a clear negative relationship between farmer's knowledge and their pesticide use. For example, as shown in Table 2, farmers in the high-knowledge group sprayed 1–10 kg/ha, or 3.3%–37.1% less pesticide than that of farmers in the low-knowledge group (rows 1 and 2). On average, farmers in the high-knowledge group sprayed 2.95 kg/ha (or 13.4%) less pesticide than that of farmers in the low-knowledge group.

The negative relationship also held if we classify the farmers' knowledge into Bt-specific knowledge and other general knowledge. As shown in Table 2, for all the six counties, farmers with more pest management knowledge (either Bt-specific or other general knowledge) almost consistently sprayed less pesticide than farmers with less knowledge. The story also held if we look at the relationship between the amount of pesticide use against bollworm and farmers' knowledge.

[1] In our study areas, all chemical pesticides should be diluted when they are sprayed in fields. “Quantity of pesticide” in this study is the quantity that farmers purchased from pesticide stores (before the dilution).

[2] Previous studies showed that cotton bollworm moths could fly more than several kilometers and they also have the ability to know the moth density of a small plot of land (Guo, 1998; Wu & Guo, 1997). Hence it is reasonable to assume that moth density (and hence larvae density) is similar within a village.

[3] This study focuses on the impact of farmer's knowledge on pesticide use. Hence, understanding the determinants of farmer's knowledge is beyond the scope of this paper.

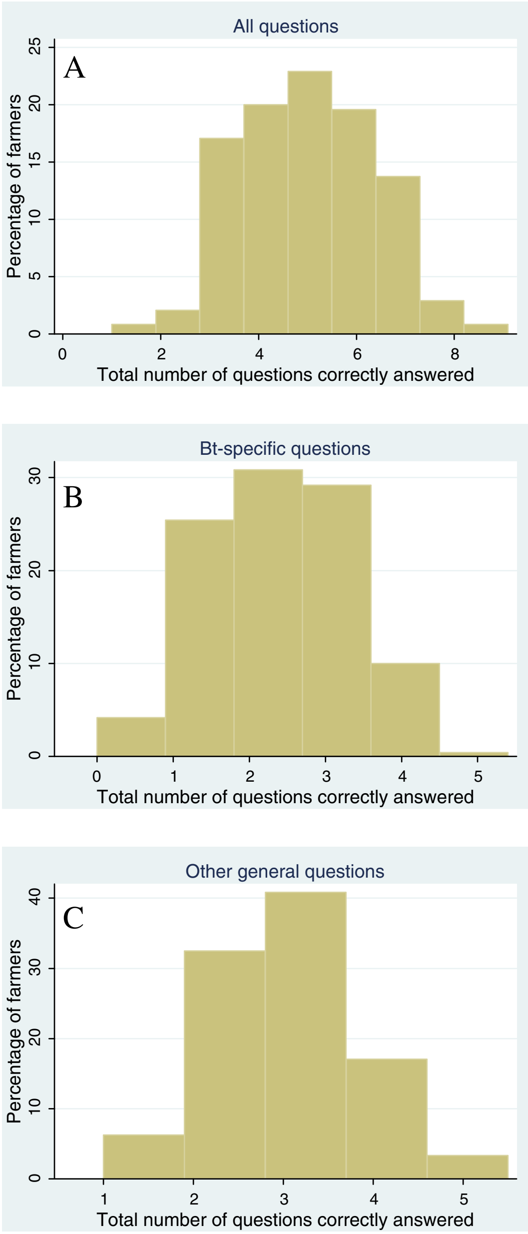

Fig. 1. Results on farmers' pest management tests.

All the above evidences seem to indicate that the large variation of pesticide use may partially be explained by farmers' knowledge. If this is true, then there is a high potential to reduce pesticide use by providing farmers with appropriate information or training on pest management and pesticide use through an agricultural extension system. However, we might be misled since the relationships above are unconditional. To control the impact of other factors on farmers' pesticide use, we are going to setup and run multivariate regression models in the following section.

3. A multivariate regression model

The model used in this study follows the general pesticide use model at the farm level as Pingali and Carlson (1985) and Huang et al. (2003). Specifically, the pesticide use model can be specified as:

$$Q_{ijt} = f\left(I_i,\ P_{ijt},\ C_i,\ V,\ Y_{2007},\ \varepsilon_{ijt}\right)$$

Table 2
Relationship between farmers' knowledge and pesticide application.

	Henan		Shandong		Hebei	
	Taikang	Fugou	Liangshan	Xiajin	Shenzhou	Xinji
Total pesticide application (kg/ha)						
Based on overall tests						
Low-knowledge farmers	17.0	19.8	10.8	26.4	19.1	39.2
High-knowledge farmers	16.0	17.0	9.5	16.6	17.6	37.9
Based on tests of Bt-specific questions						
Low-knowledge farmers	17.2	20.1	10.9	25.6	20.0	39.6
High-knowledge farmers	16.0	15.8	8.9	18.5	17.4	37.5
Based on tests of other general questions						
Low-knowledge farmers	16.5	19.6	10.6	27.2	17.1	44.3
High-knowledge farmers	16.8	18.4	10.1	19.8	19.5	37.4
Pesticide used to control bollworm (kg/ha)						
Based on overall tests						
Low-knowledge farmers	3.5	5.7	5.0	9.1	9.5	23.0
High-knowledge farmers	2.6	4.3	3.8	6.2	7.6	22.3
Based on tests of Bt-specific questions						
Low-knowledge farmers	3.5	5.3	5.0	8.5	10.2	23.1
High-knowledge farmers	2.9	5.1	3.4	7.5	7.7	22.2
Based on tests of other general questions						
Low-knowledge farmers	3.1	5.9	5.3	8.5	7.1	28.5
High-knowledge farmers	3.3	4.7	4.2	7.8	10.0	21.5

Source: Authors' survey.

where dependent variable Q_{ijt} is the amount of pesticide sprayed per hectare by i^{th} farmer in the j^{th} plot of land at year t. I represents the level of farmer's knowledge, which is measured by the percentage of test questions that the farmer has correctly answered. P is the average price of pesticide sprayed by the farmer and measured as yuan/kg. To control the impact of the household's characteristics (C), household head's age (in years) and education (in schooling years), whether or not the household head is a village leader (1 if yes, 0 if not), value of household asset (in 1000 yuan), and farm land size (in hectares) are included in

Table 3
Estimated parameters of farmers' pesticide application in Bt cotton production in 2006–2007.

	Without cluster			Using individual as cluster		
	Total pesticide use (kg/ha)	Total pesticide use (kg/ha)	Pesticide use against cotton bollworm (kg/ha)	Total pesticide use (kg/ha)	Total pesticide use (kg/ha)	Pesticide use against cotton bollworm
Percentage of correct answers of all questions (%)	−6.85 (3.59)***			−6.85 (1.99)**		
Percentage of correct answers of Bt-specific questions (%)		−4.07 (2.98)***	−1.80 (2.04)**		−4.07 (1.62)	−1.80 (1.09)
Percentage of correct answers of other general questions (%)		−2.50 (1.66)*	−0.77 (0.67)		−2.50 (0.94)	−0.77 (0.38)
Pesticide price (yuan/kg)	−0.27 (9.38)***	−0.27 (9.24)***	−0.13 (6.62)***	−0.27 (5.27)***	−0.27 (5.20)***	−0.13 (3.62)***
Farm size (hectares)	−1.19 (1.26)	−1.14 (1.21)	−0.25 (0.41)	−1.19 (0.69)	−1.14 (0.66)	−0.25 (0.21)
Household head age (years)	0.05 (1.24)	0.05 (1.23)	0.00 (0.18)	0.05 (0.68)	0.05 (0.67)	0.00 (0.10)
Household head education (years)	−0.17 (1.58)	−0.17 (1.57)	−0.08 (1.31)	−0.17 (0.85)	−0.17 (0.85)	−0.08 (0.71)
Village leader dummy (1 = yes; 0 = no)	0.11 (0.10)	0.08 (0.07)	−1.25 (2.19)**	0.11 (0.05)	0.08 (0.04)	−1.25 (1.12)
Household asset (1000 yuan)	−0.02 (1.52)	−0.02 (1.61)	−0.02 (2.81)***	−0.02 (0.83)	−0.02 (0.88)	−0.02 (0.50)
2007 year dummy (1 = 2007; 0 = 2006)	−4.02 (1.94)*	−3.96 (1.91)*	1.34 (1.22)	−4.02 (0.97)	−3.96 (0.96)*	1.34 (0.62)
Constant	32.00 (11.66)***	31.83 (11.68)**	15.30 (8.84)***	32.00 (6.38)***	31.83 (6.40)**	15.30 (4.81)***
Village dummies	Estimated but not reported					
Observations	1429	1429	1429	1429	1429	1429
R-square	0.44	0.44	0.49	0.44	0.44	0.49

Notes: *, **, and *** indicate the statistically significant values at the 10%, 5%, and 1%, respectively. The figures in the parentheses are absolute t-values.

the model. V is a vector of village dummy variables. A year dummy (Y_{2007}) is included to control for any time related variation, including year-to-year fluctuations in pest infestation, which equals l if the observation is in 2007 and 0 in 2006. Finally, ε is an error term. Summary statistics of these variables used in the regressions are included in Appendix Table 2.

We estimated farmer's pesticide use equation in three alternative specifications. The first two specifications are on total pesticide use: one is based on overall knowledge; and the other separates test questions into two groups. In other words, both the correct answer to Bt-specific questions and correct answer to other general questions are included as two separate variables in the right hand side of the second equation. In the third equation, we try to explain the pesticide use against bollworm only, rather than the total pesticide use as that in the first and second equations.

4. Results

The estimation results are presented in Table 3. All the estimated models perform well. R-squares for the 3 models are 0.44, 0.44 and 0.49, respectively (last row). These levels of R-squares are relatively high for cross-sectional data. In addition, the signs of the estimated coefficients for most variables are as expected. For example, estimated coefficients of pesticide price are significant and negative in all specifications, indicating that as the pesticide price increases, farmers spray less pesticide in their cotton fields.

More importantly, the multivariate regression supports the hypothesis that farmers' knowledge is strongly and negatively related with their pesticide use. For example, as shown in the first column of Table 3, the estimated coefficient of farmers' knowledge is −6.85 and statistically significant. In other words, the more knowledge the farmers have, the less pesticide they spray. As shown in Fig. 1, on average, farmers could only correctly answer half of the test questions. According to this study, it can be estimated that if farmers' awareness and knowledge of pest management and pesticide use had been improved to the level as those who had answered these questions correctly, the quantity of pesticide could be reduced by 3.43 kg/ha [6.85 ∗ (100% − 50%)], which is about 16% of average pesticide use per hectare in our sample (row 1, Appendix Table 2).

This finding holds if we replace farmers' overall knowledge with their Bt-specific knowledge and other general knowledge. As shown in the second column of Table 3, the estimated coefficient of farmers' Bt-specific knowledge is −4.07, and statistically significant. This estimation result shows that the more aware they are of Bt technology (or the higher percentage of Bt-specific test questions the farmers correctly answer) the less pesticide they spray. Based on this finding, if farmers' awareness and knowledge of Bt-specific questions had been improved to the level as those who had answered all these questions correctly (increases from the current 47% to 100%), the total quantity of pesticide could be reduced by 2.16 kg/ha [4.07 ∗ (100% − 47%)], or 10% of the average total pesticide use.

Table 4
Sensitive analysis of determinants of pesticide use.

	Expenditure of pesticide use (yuan/ha)			Total pesticide use (kg/ha)		Natural logarithm of total pesticide use
	Total	Total	On cotton bollworm	All except for top 1% observations	All except for top 5% observations	
Correct answers in pest management tests (%)	−194.59			−6.36	−4.93	−0.32
	(3.92)**			(2.08)**	(1.83)*	(2.00)**
Correct answers on tests related to Bt cotton (%)		−142.13	−34.81			
		(3.88)***	(1.59)			
Correct answers on tests not related to Bt cotton (%)		−55.85	−5.35			
		(1.31)	(0.20)			
Average price of pesticides (yuan/kg)	3.08	3.17	0.22	−0.26	−0.23	−0.02
	(3.11)***	(3.18)***	(0.47)	(5.37)***	(5.91)***	(7.97)***
Farm size (hectares)	−32.99	−31.60	−6.74	−0.07	0.81	−0.00
	(1.26)	(1.21)	(0.43)	(0.05)	(0.61)	(0.06)
Household head age (years)	1.14	1.12	0.38	−0.02	−0.03	−0.00
	(1.07)	(1.06)	(0.66)	(0.28)	(0.50)	(0.08)
Household head education (years)	−3.45	−3.24	−2.02	−0.14	−0.18	−0.01
	(1.19)	(1.13)	(1.32)	(0.75)	(1.19)	(0.95)
Village leader dummy (1 = yes; 0 = no)	−26.45	−27.21	−48.39	−1.27	−1.59	−0.07
	(1.07)	(1.09)	(3.63)***	(0.87)	(1.53)	(1.03)
Household asset (1000 yuan)	−0.39	−0.44	−0.50	−0.01	−0.02	0.00
	(1.42)	(1.62)	(2.90)***	(0.55)	(1.07)	(0.05)
2007 year dummy (1 = 2007; 0 = 2006)	−47.39	−46.49	59.39	−0.63	1.03	0.00
	(0.98)	(0.96)	(2.38)**	(0.23)	(0.54)	(0.01)
Constant	557.73	557.666	251.109	33.00	31.19	3.61
	(7.26)***	(7.33)***	(5.74)***	(6.67)***	(7.73)***	(14.33)***
Village dummies	Estimated but not reported					
Observations	1429	1429	1429	1413	1358	1429
R-square	0.41	0.41	0.46	0.48	0.48	0.52

Notes: *, **, and *** indicate the statistically significant values at the 10%, 5%, and 1%, respectively. The figures in the parentheses are absolute t-values.

Similarly, more other general knowledge also lead to reduction of pesticide use. As shown in column 2 of Table 3, the estimated coefficient of other general knowledge is −2.50, which is also statistically significant (row 3). According to this finding, farmers could reduce their pesticide use by 1.1 kg/ha [2.50 ∗ (100% − 56%)] should their awareness on other general questions be improved to the level as those who had answered these questions correctly (increases from the current 56% to 100%). In short, the estimated result shows that the high use of pesticide observed in China's cotton production can be partially explained by farmers' lack of knowledge of pest management and pesticide use. The same story goes if we estimate the impact of farmers' knowledge on pesticide use against cotton bollworm in cotton production (column 3 of Table 3).

Because one household usually has more than one plot of cotton, the pesticide use in one plot is correlated with the pesticide use of other plots. For example, if a farmer sprayed more pesticides in one plot, he/she might also spray more pesticides in another plot. Hence, we re-estimated the models individually as the level of clustering (columns 4–6, Table 3). Because of this, the estimated coefficients are the same, but the t-ratios have decreased a little bit, as shown in Table 3 (columns 1–3 versus columns 4–6). However, more importantly, the nature of the results (especially for our variable of interest — farmer's knowledge) when we correct and do not correct for "cluster" effects is similar.

To test the robustness of our estimation results, we also run a few scenarios. Under the first scenario, we include the unit cost of pesticide use as an alternative dependent variable. As shown in Table 4, the estimation results are very similar to that of using pesticide quantity as the dependent variable (columns 1–3). Importantly, the estimated coefficients of farmer's knowledge, the variable of interest, are still negative. To check whether the results would be sensitive to some outliers in terms of pesticide use, we also run our model by 1) excluding the top 1% observations; 2) excluding the top 5% observations; and 3) taking the natural logarithm of the pesticide use. The estimation results show that most of the variables have the same sign and similar significant levels (columns 4–6, Table 4). And the nature of the results (especially for our variable of interest — farmers' knowledge) in all these scenarios is similar.

5. Discussion

Empirical studies showed that it is common for farmers to use high amounts of pesticides in developing countries (Bernard & David, 2001). As small-scale producers, Chinese farmers also use high amounts of pesticide in cotton production (Huang, Hu, et al., 2002). Even though adoption of Bt cotton allows farmers to significantly reduce pesticide use, it is observed that farmers continue to use high amounts of pesticides in Bt cotton fields. This study shows that improving farmers' knowledge of pest management and pesticide use has a significant negative impact on the amount of pesticide that farmers' spray. Based on this study, farmers' total pesticide use could be reduced by 10–15% should their knowledge be improved. This figure can be translated into a national pesticide saving of more than 20 thousand tons or near 600 million yuan.[4] It is worth to note that the benefit from improving farmers' knowledge could be much larger as the environmental and social benefits from pesticide reductions are excluded in this study.

This study has important policy implications. The Chinese government has substantially increased its investment in agricultural technologies in recent years, which made China one of the leading countries in agricultural biotechnology (Huang, Rozelle, et al., 2002). However, the agricultural extension service in rural areas is still very weak (Hu, Yang, Kelly, & Huang, 2009). As shown in this study, on average, there is great room for farmers to improve their knowledge and reduce pesticide use in crop production. While Bt cotton adoption has significantly reduced pesticide use, the estimation results of this study also imply that not all farmers could reach the maximal benefits offered by new technology. In other words, providing new technology to farmers is necessary but not sufficient, and offering training and technological extension services related to the new technology is also essential.

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[4] China's cotton sown area is 5.92 million ha in 2007 (National Bureau of Statistics of China, 2008). Hence, the saving on pesticide use is 20.52 million kg (3.46 kg/ha ∗ 5.92 million ha = 20.52 thousand tons), or 580 million yuan (20.52 million kg ∗ 29.10 yuan/kg = 597.13 million yuan) should farmers answer all questions correctly.

Appendix A

Appendix Table 1
Tests questions and farmers' answers.

	Questions	Choices and correct answer(s)	Average correct answer rate (%)	Standard deviation
1	Which pest(s) can Bt cotton effectively control?	(1) Bollworm; (2) pink bollworm; (3) spider mite; (4) aphid; (5) mirid; (6) white fly; (7) thrips; (8) *Trichogramma*; (9) others	17	0.38
2	Why Bt cotton can effectively control bollworm?	(1) Bollworms are starved since they refuse to eat Bt cotton; (2) bollworms are poisoned and killed since they eat Bt cotton; (3) don't know; (4) others	81	0.39
3	Generally, in which generation of bollworm is Bt cotton the most effective?	(1) 2nd generation; (2) 3rd generation; (3) 4th generation; (4) don't know; (5) others	66	0.48
4	Pesticide application in Bt cotton field should be based on:___	(1) Density of bollworm eggs; (2) number of larvae per 100 plants; (3) extent of the damage on cotton bolls; (4) don't know; (5) Others____	36	0.48
5	At the 2nd generation of bollworm, if there are 5–10 larvae per 100 plants, is there a need to spray insecticide?	(1) Yes; (2) no; (3) don't know; (4) others	23	0.42
6	What color is the egg when bollworm is about to hatch out?	(1) Milk white; (2) earth yellow; (3) black; (4) don't know; (5) others	51	0.50
7	Is *Trichogramma* the natural enemy of bollworm?	(1) Yes; (2) no; (3) don't know; (4) others	16	0.36
8	Is esbiothrin the conventional pesticide for bollworm?	(1) Yes; (2) no; (3) don't know; (4) others	96	0.19
9	When is the best time to control mirids?	Per 100 plants, there are (1) 1–2 mirids; (2) 5–10 mirids; (3) 15–20 mirids; (4) others	30	0.46
10	Does bollworm only eat cotton bolls and never eat flowers and leaves?	(1) Yes; (2) no; (3) don't know; (4) others	88	0.32

Note: Correct answer(s) are underlined (column 2).
Source: Authors' survey.

Appendix Table 2
Statistics on variables used in the regression.

	Mean	Standard deviation
Characteristics of households		
Village leader dummy (1 = yes; 0 = no)	0.09	0.94
Farm size (ha)	0.77	0.36
Age of household head (years)	48.71	8.29
Education of household head (years)	7.50	2.79
Household assets (1000 yuan)	38.5	31.6
Pesticide use and farmers' knowledge		
Pesticide use (kg/ha)	21.17	14.99
Pesticide use against bollworm (kg/ha)	9.20	9.70
Correct answer of all tests questions (%)	50	15
Correct answer of Bt-specific questions (%)	47	22
Corrected answer of other general questions (%)	56	19
Pesticide price (yuan/kg)	29.10	10.56

Source: Authors' survey.

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