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Adoption and Uptake Pathway of GM Technology by Chinese Smallholders: Evidence from Bt Cotton Production

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Bt cotton was commercially released in 1997. After this, it was successfully adopted in China, helping Chinese farmers recover their cotton production in the late 1990s. Descriptive statistics and findings from focus group discussions show that farmers prefer Bt cotton mainly because it is effective in controlling bollworm and reducing yield loss from bollworm attacks, it reduces pesticide usage, and it is an environmentally friendly crop. In the first stage of Bt cotton diffusion, seed companies and technology developers (e.g., research institutes and biotech companies) both played an important role in convincing farmers to use Bt cotton. After the first farmers to adopt Bt cotton demonstrated its outstanding performance, other farmers soon followed suit. However, it is worth noting that when Bt cotton was first released, there were constraints on its adoption, such as limited knowledge about biotechnology.

Key words: Bt cotton, adoption, diffusion, innovation tree, China.

Introduction

There has been rapid growth of genetically modified (GM) crop area since the late 1990s. With a remarkable 100-fold increase from 1996 to 2013, the global total GM crop area reached 175.2 million ha in 2013, distributed across 27 countries (James, 2013). China was one of the first countries to use commercialized GM crops. Bt cotton was commercially released in 1997, and was soon adopted by farmers. As of 2004, Bt cotton constituted 65% of the total cotton area. Nearly all farmers planted Bt cotton in the North China and Yangtze River basin after the mid-2000s. Bt cotton is a well-documented success story of biotechnology adoption in China.

The rapid growth of GM technology has also attracted the attention of agricultural economists, who evaluate the costs and benefits of major GM crops (Falck-Zepeda, Traxler, & Nelson, 2000; Fernandez-Cornejo, Alexander, & Goodhue, 2002; Huang, Rozelle, Pray, & Wang, 2002b; Qaim & de Janvry, 2003; Huang, Hu, Rozelle, & Pray, 2005; Marvier, McCreedy, Regetz, & Kareiva, 2007). Numerous results, both *ex post* and *ex ante*, show that insect-resistant *Bacillus thuringiensis* (Bt) crops allow for a significant reduction in the use of pesticide, which has a positive impact on welfare and the environment. For example, Huang, Hu, Pray, Qiao, and Rozelle (2003) indicated that using Bt cotton rather than pesticides appears to improve both productivity and the environment; this finding is shared by the study of Bt cotton in India by Subramanian, Kirwan, Pink, and Qaim (2010). Compared to traditional cotton, smallholders benefit from savings on pesticide, higher effective yields with less crop loss, and a reduction in poverty (Ali & Abdulai, 2010). Similar benefits have been found in Bt maize production in the Philippines (Torres, Centeno, Daya, Osalla, & Gopela, 2012).

Despite the enormous uptake in GM crop cultivation in many countries, differences in institutional and developmental interventions means the pathways and diffusion of new biotech products to smallholders also differ. There is still much debate about the potential risks of GM crops as well as their possible direct and indirect agronomic and socio-economic effects. As a result, negative attitudes seem to dominate in the European Union (EU), and thus GM technology is denied to European smallholders. For example, farmers in Romania cultivated herbicide-tolerant (HT) soybeans for some years (1999-2006) before becoming part of the EU. These farmers then had to stop planting HT soybeans because HT soybeans were not approved in the EU. After the commercial release of Bt cotton in China and India, some smallholders did not adopt this technology for years, even within the same communities as those who did and without any constraints on access to GM seeds (Chen, Huang, & Qiao, 2013; Kouser & Qaim, 2013). This could be explained by factors such as gaps in the marketing chains of seed companies, the functioning of the technical extension system, and individual household characteristics.

The adoption and diffusion of biotechnology is influenced by socio-economic factors and farmers' risk preferences. Empirical results and evidence from focus group discussions (FGDs) suggest that smallholders will not pay for a specific seed unless they verify that it has real benefits (Torres et al., 2012). Chen et al. (2013) found that if smallholders can fully grasp and apply GM knowledge in production, the use of pesticide would decline by 6.7 kg/ha by using Bt cotton. However, the positive effects on pesticide use and crop yields can only occur when a new technology, such as a GM crop, is "absorbed" by smallholders. Even having adopted Bt cotton, the overuse of pesticide by leading smallholders reduces the positive effects of biotechnology on welfare and environment, as well as making fellow smallholders less likely to follow suit. In an experiment to measure smallholders' risk preferences, Liu (2013) found that, after controlling for other constant variables, those who are risk-averse are more likely to adopt Bt cotton at a later stage.

Existing literature shows that smallholders often vary substantially in how they adopt new agronomic technology, owing to differences in their resource endowment. The result is potentially less profit, which may impede the introduction of advanced technology (Pemsl, Waibel, & Gutierrez, 2005). With scarce land resources of around 0.60 ha per farm, Huang, Zhang, Yang, Rozelle, and Kalaitzandonakes (2008) argued that smallholders who are vulnerable to harvest risk from pest infestation are more inclined to overuse pesticide. Thus, research on the adoption of GM crops and the effect of knowledge about the technology is meaningful and valuable to countries with a similar land/labor ratio—like India.

Even though existing studies have empirically analyzed the key factors that influence the adoption decisions of smallholders, there has been little research on the uptake process and the roles of different stakeholders. To fill this gap, this study answers the following questions: What institutional frameworks can better offer biotechnology in China? Who are the leading adopters of Bt cotton in the local communities? What are the key factors that facilitate or constrain the adoption of biotechnology? What are the roles of different stakeholders in the uptake process of biotechnology? What are the significant changes that have occurred as a result of adopting GM crops? What are the biotechnology uptake pathways in a village? What are the views of stakeholders and smallholders with regard to expanding or adopting biotechnology?

Thus, the overall objective of this study is to analyze the adoption and uptake pathways of biotech crops among smallholders in China. The specific objectives include 1) to present the evolution of cotton production, focusing on the commercial release of Bt cotton in China; 2) to explore the factors—including demographic and farm characteristics—that are correlated with the adoption of Bt cotton; and 3) to identify, by means of FGDs, the development interventions by different stakeholders, such as leading farmers, technicians, and seed dealers, in the uptake pathway of Bt cotton in China.

To meet the general and specific objectives, we use two datasets. These include national cotton production data and several rounds of cotton production surveys, as well as the FGD records. We conducted descriptive statistics of the cotton-production data and analyzed the FGD records using the innovation tree methodology. The latter methodology helps to visualize the pathway of a technology and the roles of participants in the diffusion of biotechnology in a village.

For this study, Bt cotton is used as a case crop. After the diffusion of biotechnology globally for more than a decade, smallholders are now cultivating major crops such as GM soybean, cotton, and maize with single or stacked traits. However, Bt cotton is the only major crop in the field in China, while other biotech crops (such as Bt rice) are only in the pipeline. Better understanding of the uptake of Bt cotton will have important implications for policies to expand other biotech crops in China, such as GM maize and Bt rice.

Next, we present the biosafety regulations in China, followed by a section to document the evolution of Bt cotton in China and its impacts. Then, we present the data and instruments for the survey and the FGDs. Following that, we present the results of innovation tree, based on the FGDs in four counties. Lastly, we conclude the article and discuss the potential policy implications of our findings.

Biosafety Regulations in China

In response to the emergence of agricultural biotechnology, China established in the early 1990s—and then improved—its legal and regulatory system for agricultural biosafety. The first biosafety regulation on measures for the safe administration of genetic engineering was issued by the Ministry of Science and Technology (MOST) in 1993. Following MOST's guidelines, in 1996, the Ministry of Agriculture of the People's Republic of China (MOA) issued implementation measures for safety control, which are specific to agricultural GM organisms. With the continued development of agricultural biotechnology, increasing GM product imports, and consumers' concerns, China has periodically amended its biosafety regulations since 2001. Currently, biosafety regulations cover management, trade, and labeling of GM products.

Furthermore, China formally institutionalized the National Biosafety Committee (BC), which is responsible for biosafety management. The BC consists of scientists in relevant fields, including agriculture, medicine, and health, as well as representative officers from different ministries. The BC is responsible for approving the intermediate trials, environmental release, pre-production trials, and biosafety certificates of GM crops. The MOA makes decisions on the commercial release of biotech crops with the merits of the BC. In the past 15 years, even though the rest of the world has acknowledged China's government-issued biosafety certificates for Bt cotton, Bt rice, ring-spot-virus-resistant transgenic papaya, phytase maize, and other GM plants (e.g., GM petunia, tomato, sweet pepper, and poplar trees), Bt cotton remains the only major crop in the field.

Biosafety regulations are restricted to a specific duration and to certain crops. These restrictions may be extended, but only with the approval of the MOA. For crops that only have biosafety certificates, the certificate has to be renewed after expiration. For example, MOA will has renewed the biosafety certificates of Bt rice and phytase maize after they expired in August 2014.

However, with the rapid development of GM technology both domestically and abroad, and the commercial release of GM crops, the present biosafety regulations of GM crops will bring new challenges with regard to the trade of GM crops. China has developed its own strong biotech program and biosafety regulation system for GM commercial production and imports. However, it has yet to seek approval for its GM products in any other country, which is particularly concerning for potential exports of GM crops. The practice of only applying safety licenses domestically and not to the importing country is likely to cause a low-level presence (LLP) of GM products, as well as future trade disputes or suspensions (Huang &Yang, 2014).

China is one of the most important importing countries of GM crops in the world. It is becoming the biggest importer of GM soybeans and has been importing increasing amounts of GM maize during the past five years. However, the biosafety regulations of China's agricultural imports require that GM products should apply for import safety approval only after they have been approved in the exporting country. This leads to a remarkable asynchrony in the examination and approval of GM products. At the same time, the zero-threshold LLP standard adopted in China has recently resulted in the rejection of imported GM products, particularly GM maize.

Evolution of Cotton Production and Adoption of Bt Cotton in China

Commercialization Process of Bt Cotton in China

In spite of concerns over potential environmental and health risks, there has been enormous growth in the diffusion of GM crops in terms of crop varieties, acreage, and approved countries (James, 2013). GM varieties include crops such as maize, fruits such as melon and papaya, and flowers such as carnation, with improved adaptation to local agronomic conditions. The unprecedented growth of GM varieties indicates that it might be a new driving force for agricultural development and a potential solution to global food security issues (Beyers, Ismael, Piesse, & Thirtle, 2002; Huang, Hu, Rozelle, Qiao, & Pray, 2002a; Huang et al., 2005; Pray et al., 2011; Qaim & Zilberman, 2003).

To increase agricultural productivity and ensure national food security through GM technology, China has invested heavily in R&D and in building human capacity (Hu, Cai, Huang, & Wang, 2012; Huang et. al., 2002a; Huang, Hu, Cai, & Wang, 2012). Unlike many other countries, the Chinese government has, since the 1980s, invested substantially in the public sector to develop its own technology. This investment accelerated after China initiated its new National GM Variety Development Program (GM program), costing about US$3.8 billion and running from 2008 to 2020.

While most smallholders farming GM crops are adopting GM technologies from multinational companies (MNCs), China's public sector generated its own impressive GM technology. Bt cotton in China is one of the most cited examples of R&D progress with regard to GM technology. In 1997, two varieties of Bt cotton with different sources of Bt genes could be obtained by Chinese smallholders in certain provinces: one variety patented by the Chinese Academy of Agricultural Science (CAAS) competed with the variety developed by Monsanto Company (NC33B) that integrates the Monsanto Cry1Ac gene.[1] The MOA simultaneously approved these two varieties for production: the one owned by CAAS was allowed to be cultivated in the Shanxi, Anhui, Shandong, and Hubei provinces, while the NC33B variety was allowed in the Hebei province.

1. *The variety is not specified as to its genetic strain.*

Table 1. The first Bt cotton variety approved for commercial production in each province in China.

Province	Cotton production zone	Starting year	GM variety[a]	Affiliation
Anhui	Huang-Huai-Hai	1997	Bt cotton[b]	Biotechnolgy Research Institute, CAAS
Shanxi	Huang-Huai-Hai	1997	Bt cotton[b]	Biotechnolgy Research Institute, CAAS
Shandong	Huang-Huai-Hai	1997	Bt cotton[b]	Biotechnolgy Research Institute, CAAS
Hubei	Huang-Huai-Hai	1997	Bt cotton[b]	Biotechnolgy Research Institute, CAAS
Hebei	Huang-Huai-Hai	1997	NC33B	Monsanto
Henan	Huang-Huai-Hai	1999	GK12, GK95-1	Biotechnolgy Research Institute, CAAS
Liaoning	Huang-Huai-Hai	1999	GK95-1	Biotechnolgy Research Institute, CAAS
Jiangsu	Yangtze River Valley	1999	GK-12	Biotechnolgy Research Institute, CAAS
Xinjiang	Xinjiang	1999	GK-12 GK95-1	Biotechnolgy Research Institute, CAAS
Shaanxi	Huang-Huai-Hai	2004	GKz1, GKz2	Biotechnolgy Research Institute, CAAS
Jiangxi	Yangtze River Valley	2004	DP410B	Monsanto
		2004	GKz18	Biotechnolgy Research Institute, CAAS
Hunan	Yangtze River Valley	2004	DP410B	Monsanto
			GKz17	Biotechnolgy Research Institute, CAAS
Sichuan	Yangtze River Valley	2004	DP410B	Monsanto
		2004	GKz34	Biotechnolgy Research Institute, CAAS
Zhejiang	Yangtze River Valley	2004	GKz18	Biotechnolgy Research Institute, CAAS

Source: MOA (2012)

Note: [a.] In China, GM biosafety approval is case by case (e.g., by variety in each province or region)

[b.] The variety is not specified.

Since 1997, China has commercialized various GM crops, and thus the country's investment has received a high return (Pray, Huang, Hu, & Rozelle, 2002). By 2006, China had commercially produced six GM products—cotton, petunia, tomato, pimento, poplar, and pawpaw, among which Bt cotton was the most successful and widely adopted by smallholders. In fact, Bt cotton was approved for commercial release (step by step) by the Chinese MOA. The country has a long history of cultivating cotton in three regions, namely the Huang-Huai-Hai, Yangtze River, and Xinjiang cotton production zones. After the commercial release of Bt cotton in the Huang-Huai-Hai cotton production zone, it has been shown that Bt cotton requires less pesticide, saves on labor, and has an increased yield (Huang et al., 2002a). As a result, the approval of new varieties was accelerated after 2000 (Huang et al., 2002a). From a regional perspective, China's government then expanded the production of Bt cotton beyond Huang-Huai-Hai to the Yangtze River and Xinjiang cotton production zones. Table 1 indicates that in 1999, one and two varieties were allowed to be cultivated in the Jiangsu province (Yangtze River production zone) and Xinjiang, respectively. Since 2004, four varieties that adapted to the agronomic conditions were produced in the Yangtze River production zone.

From a temporal perspective, since 2000 the number of new varieties approved every year has increased dramatically in all three cotton production zones (see Table 2). In 2005 and 2006, there were more than 20 new varieties available to smallholders in provinces located either in the Huang-Huai-Hai or in the Yangtze River production zones every year.[2] From 2008 onwards, approved varieties were released subjective to the production zones, rather than by province. This suggests the characteristics of Bt cotton have been improved to be able to adapt to more diversified agronomic conditions. Furthermore, given the increased number of varieties on the market, Chinese smallholders have fewer constraints to accessing Bt cotton seed.

The results in Table 2 also show that more varieties have been approved targeting smallholders in the Huang-Huai-Hai cotton production zone. Chinese smallholders are growing Bt cotton developed by the

2. *We only report the new varieties approved every year. Even though some of the varieties approved earlier may have expired according to GM technology regulations, we reasonably assume that there were more varieties available to smallholders than those approved every year.*

Table 2. The evolution of varieties' numbers newly commercialized by cotton production zones and provinces, 1997-2012.

	Huang-Huai-Hai cotton production zone								Yangtze river cotton production zone					Xinjiang
Year	**Anhui**	**Hebei**	**Henan**	**Shandong**	**Shanxi**	**Hubei**	**Liaoning**	**Shaanxi**	**Jiangsu**	**Jiangxi**	**Hunan**	**Sichuan**	**Zhejiang**	**Xinjiang**
1997	1	1	-	1	1	1	-	-	-	-	-	-	-	-
1998	0	0	-	0	0	0	-	-	-	-	-	-	-	-
1999	3	1	2	1	1	0	1	-	1	-	-	-	-	2
2000	1	2	0	1	0	0	0	-	0	-	-	-	-	0
2001	1	0	0	0	0	0	0	-	0	-	-	-	-	0
2002	2	2	7	4	1	1	0	-	1	-	-	-	-	1
2003	0	0	0	1	0	0	0	-	1	-	-	-	-	0
2004	19	18	28	28	0	10	0	2	18	2	2	2	1	0
2005	72	22	33	36	3	11	0	8	31	2	5	2	3	1
2006	74	29	61	44	24	26	0	5	20	1	18	4	4	0
2007	27	50	53	30	7	14	0	11	24	5	10	3	2	0
2008	180								53					0
2009	141								90					0
2010	92								72					0
2011	31								10					0
2012	54								69					0

Source: MOA (2012)

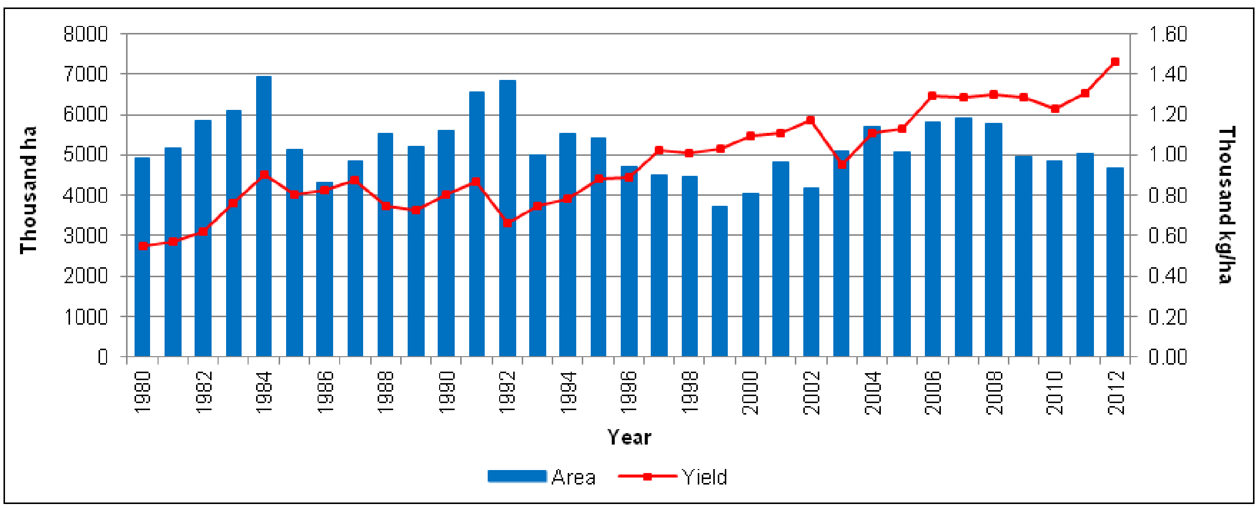

Figure 1. Cotton area and yield, 1980-2012.
Source: MOA (1981-2013)

domestic public research institutes, as well as those from MNCs such as Monsanto (Huang et al., 2002a).

Evolution of Cotton Production and the Adoption of Bt Cotton in China

With a long history of cultivating cotton in China, the commercialization of Bt cotton included adapting it to local agronomic and pest conditions. After the introduction of the household responsibility system, the trends of cotton area show that cotton production reached historical levels in 1984 and 1992. The yield increased from 550 kg/ha in 1980 to 880 kg/ha in 1991, with an average yearly growth rate of 4.8%, even though there is some fluctuation in the yield in the latter part of the 1980s (see Figure 1). Some researchers attributed the growth of cotton production to the institutional reforms and the introduction of hybrid varieties (Fok & Xu, 2011). Cotton production recovered at the same time as the production of Bt cotton. Even in the initial stage of offering Bt cotton, the cotton production area increased by more

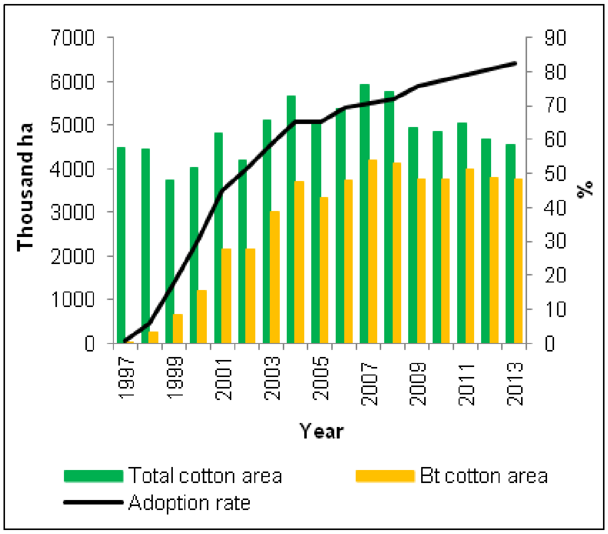

Figure 2. The trend of Bt cotton areas and the adoption rate of Bt cotton in China, 1997-2013.
Source: Authors' own calculation.

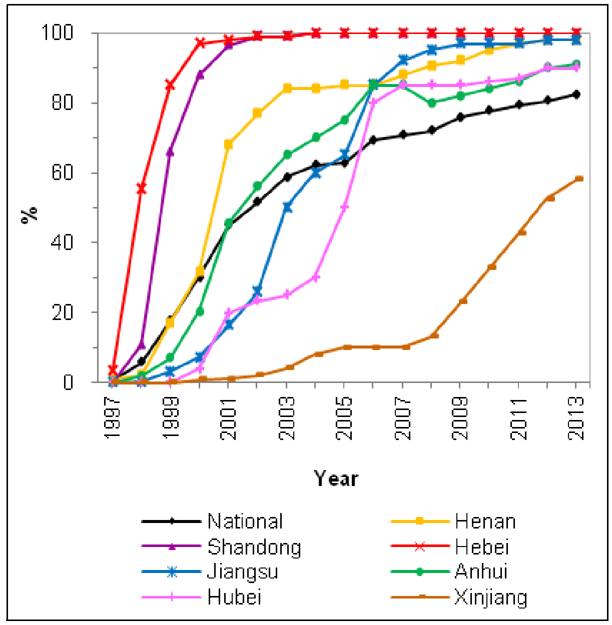

Figure 3. The adoption rate of Bt cotton by provinces, 1997-2013.
Source: Authors' own calculation.

than 35% to 5.1 million ha between 1998 and 2003 mainly in the Huang-Huai-Hai cotton production zone (see Figure 1). After the further expansion of Bt cotton to the Yangtze River cotton area, the total production area covered more than 5.5 million ha between 2006 and 2008. However, more recently, the area under cultivation decreased to less than 5.0 million ha. Our field observations suggest that this reduction in cotton production is because smallholders tend to save on labor input in agricultural production, given the increased opportunity cost of farming. Compared to other cereals in China, cotton is a labor-intensive crop. The cotton yield kept increasing, albeit with a drop in 2003 (see Figure 1). This yield reached a record high of more than 1,300 kg/ha in 2006.

Figure 2 indicates that the trend of increasing cotton production areas from 1999 to 2004 correlates with the rapid adoption of Bt cotton in China. Since Bt cotton was introduced in the market, the area of Bt cotton has increased more than 12 times, from 260,000 ha in 1998 to 3.8 million ha in 2008. Here, the adoption rate is defined as Bt cotton area to total cotton area. The adoption rate indicated that, until 2008, more than two-thirds of the cotton area was Bt cotton, with its improved characteristics and adaptation to local production conditions. During the first decade of the initial commercialization of Bt cotton in China, the rapid adoption of Bt cotton mainly happened in the Huang-Huai-Hai and Yangtze River cotton production areas. The further increase in the adoption rate at a national level—from around 70% to 86% in the past six years—was driven mainly by the increase in the adoption rate in Xinjiang.

Decomposing the adoption rate at the provincial level reveals important characteristics (see Figure 3). There exists a regional variation of adoption. In 1997, the share of Bt cotton in the Huang-Huai-Hai cotton production zone was only 5%, and was zero in the Yangtze River and Xijiang zones. One year later, the share of the adopted area had increased to 42.9% in the Huang-Huai-Hai zone and 2.6% in the Yangtze River zone (Huang, Yang, & Rozelle, 2010). Even though Bt cotton has been commercialized in Xinjiang since 1999, the adoption rate there was still low, at 13%, owing to fewer pest problems in 2008. From 2008 onwards, the adoption rates were between 96% and 98% in the Huang-Huai-Hai and Yangtze River production zones. The adoption rate in Xinjiang increased from 13% in 2008 to 58% in 2013, with a compound average annual growth rate of 35%.

As mentioned in the above section, even though five provinces were allowed to cultivate Bt cotton at the same time, the adoption rate in the Hebei and Shandong provinces was faster than those in other provinces. Until 2000, the percentage of the Bt cotton area to the total cotton area was only 20%, and less than 5% in Anhui and Hubei province. Bt cotton production in Henan lagged one year behind that in the first region. However, the adoption rate is growing faster than the

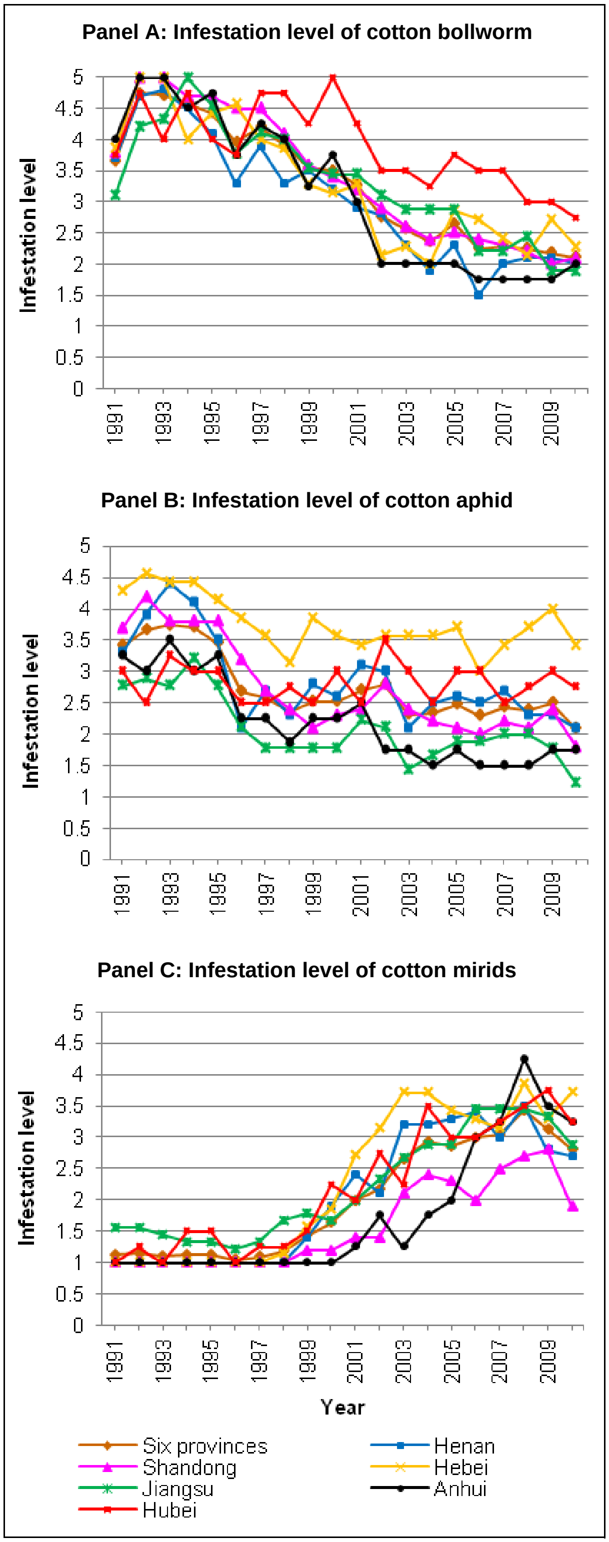

Figure 4. The infestation of bollworm, cotton aphid, and cotton mirids, 1991-2010.

Source: Chinese Academy of Agricultural Sciences (2011)

average national adoption rate at the national level. The almost complete adoption of Bt cotton also occurred in the Hebei and Shangdong provinces, dating back to 2003.

Combining Figure 3 and Figure 4 (Panel A), there appears to be an inverse correlation between Bt cotton adoption and the level of infestation of the cotton bollworm. With the continuous infestation of pests—especially the cotton bollworm since 1992—cotton production stagnated (see Figures 2 and 4). Before the introduction of Bt cotton in 1998, cotton production shrank to 3.7 million ha, which was roughly half of the historical record; that occurred across all provinces. Areas with higher levels of infestation of the cotton bollworm in the past adopted Bt cotton more quickly across all provinces. However, the adoption of Bt cotton is not correlated with the infestation levels of cotton aphid, and cotton mirids (see Figure 3 and Figure 4 [Panels B and C]).

Impacts of Bt Cotton in China

The benefits of Bt cotton illustrates the potential role of biotechnology in boosting agricultural productivity and improving national food security (Huang et al., 2002a). One of the proven traits of Bt cotton is its remarkable ability to reduce the usage of pesticide. Compared with conventional cotton, this single trait of Bt raises the effective yield by reducing crop loss and its variation of yield. Using damage control models, Bt cotton adopters in China save, on average, around 56% in pesticide, with a yield increase of roughly 8% (Huang et al., 2002a). Compared with those in India, the Bt cotton yield in China increased by more, but the pesticide saving was a bit less (Sadashivappa & Qaim, 2009).

After years of Bt cotton production, other benefits have become evident that make Bt cotton a valuable option for smallholders (Pray, Nagarajan, Huang, Hu, & Ramaswami, 2011). Even though the price of conventional cotton is lower, higher yields of Bt cotton combined with less pesticide use and labor input outweigh the higher seed costs in developing countries. This suggests that adopting Bt cotton improves smallholders' welfare through its positive effects on income. By measuring consumption expenditure, the long-term impacts on Bt cotton adopters' welfare has been shown to be positive compared to smallholders in India (Kathage & Qaim, 2012). Owing to limited consumption data, this issue has not yet been explored for Chinese Bt cotton adopters.

Despite the debate around environmental effects, the direct and indirect positive effects on the environment have been shown by virtue of its unique pest-control mechanism. For example, with the obvious advantage of controlling bollworm, cotton smallholders (Bt or non-Bt) and other smallholders benefit from the reduction of the bollworm population where the agricultural production is susceptible to this pest (Lu, Wu, Jiang, Guo, & Desneux, 2012). A recent study by Zhou et al. (2014) also shows the positive impacts of Bt cotton on biodiversity in the field. There are also positive environmental effects on water, energy use, and soil resulting from reduced pesticide spraying.

Given the nature of Bt cotton adoption in China, those interested in the diffusion of technology, including those engaged in the debate about biotechnology, should be interested in obtaining the answers to the following questions: Who are the leading farmers adopting biotechnology and what are their roles in the diffusion? What are the important factors that facilitate or constrain the adoption of Bt cotton? What are the roles of different stakeholders in the uptake process of Bt cotton?

Sampling Strategy, Instruments, and Procedure for Focus Group Discussion

This study analyzes the patterns and dynamics of adopting GM technology by Chinese smallholders in cotton production. We further identify the uptake pathway of GM technology among a selected segment of Chinese cotton smallholders. To meet the specific objectives, we organized focus group discussions (FGDs) within the selected sampled villages.[3] The sampling strategy is subject to cotton area, Bt cotton production, and its varieties patented by companies or institutes. First, we chose four provinces including Hebei, Shandong, Anhui, and Henan located in the Huang-Huai-Hai cotton production zone. Bt cotton production in all four provinces was either in 1997 or in 1999, when Bt cotton was first released in China.

In 1998, two varieties of Bt cotton from two sources of Bt genes were available to smallholders in the three sampled provinces (see Table 1). One variety, distributed by the CAAS could be accessed in the Anhui and Shandong provinces. The other variety (NC33B), integrating the Monsanto Cry1Ac gene, was approved for production only in Hebei. One year later, smallholders in Henan were able to access three varieties (GK12, GK95-1, and SGK321) developed by the CAAS. In 2000, Monsanto also successfully commercialized their varieties, including PM1560BG, NC33B, and DP410B in Anhui and NC33B in Shandong following the first release of NC33B in Hebei. Compared with other cotton production regions, more varieties have been offered to smallholders in the sampled provinces, with improved adaptation to local agronomic conditions and better resistance to bollworm. Secondly, in each province, two counties were chosen because of the different varieties of Bt cotton and cotton area. In a common annual two-crop rotation, cotton is harvested in autumn. This suggests that in some regions, where risks such as early frost exist, smallholders are less likely to produce cotton. Thirdly, we randomly selected four villages in each county. Finally, in each village, we relied on the household roster to randomly select 20 cotton smallholders.

To generate the innovation tree pathway, we organized one focus group discussion in one village in each county. The innovation tree is a participatory rural appraisal (PRA) tool developed by Van Mele and Zakaria (2002, p. 58). This methodology is well documented as "a useful tool to distinguish between different types of innovators, but also to better understand the psychological and social dimensions underpinning the decision-making process, which would be difficult to disclose in other ways." For this study, we selected the results of four focus-group discussions in Hebei and Anhui provinces. To identify the respondents in the focus-group study, we interviewed the village cadres and the technicians at the township. The focus group consisted of the technician in the village, village cadres, the smallholders who adopted Bt cotton first in the village, other smallholders, and the smallholders who sell pesticide and chemical fertilizer in the village. The procedure for the focus group study is as follows:

- All respondents gathered in a specific place.
- The leader of the survey team explained the research protocols and the purpose of the group discussion.
- Respondents were given one piece of colored paper to record personal characteristics.

3. *Details of the survey and results can be found in our project report titled "Adoption and Uptake Pathway of GM technology by Chinese Smallholders: Evidence from Bt Cotton Production" (Wang et al., 2014). For the whole project, we organized eight FGDs when we implemented this project in 2012. Since the adoption and uptake pathway in the four villages in Henan and Shandong provinces were similar to those in Hebei province, and owing to space constraints, we use only four representative FGDs from Hebei and Anhui provinces.*

- Smallholders and fellow smallholders were asked about their adoption of Bt cotton, including the year they started doing so, the area of Bt cotton and non-Bt cotton in the first year of adoption, the seed varieties and their source and availability, their inputs and output, and their marketing scheme.
- Questions were designed for village leaders and technicians regarding the barriers to, and driving forces behind, expanding GM technology within the village.
- Dialogue was organized to determine the impacts of GM technology on cotton production and smallholder's welfare.
- Smallholders were asked for their views on GM technology.

The questions for the FGDs are presented in Appendix A1.

Uptake Pathways of Bt Cotton: Evidence from the Focus Group

Introduction of the Innovation Tree

The innovation tree is a method that helps to visualize and analyze the way in which an innovation such as biotechnology spreads over time among community members (Torres et al., 2012; Van Mele & Zakaria, 2002). An FDG organized within a village allowed us to draw an innovation tree to identify the uptake pathway of Bt cotton by Chinese smallholders. Furthermore, the discussions during the FDGs provided evidence on the roles of different stakeholders, including village cadres, seed dealers, and technicians in the diffusion of biotechnology. The perspectives of biotech smallholders, as discussed in the FDGs, have important policy implications in terms of promoting the diffusion of biotechnology in the future. The coordination of the 2012 National Cotton Survey made it possible for the same survey group to organize the FGDs. In this article, we present the findings of four of the FGDs. Following Torres et al. (2012), who studied uptake pathways of biotechnology in the Philippines, the results of the FGDs are explained using an innovation tree and flowcharts. The arrows in the figures are coded as follows:

- Thick black arrows represent the flow of information between and among smallholders in the FGD.
- Thin black arrows represent the flow of information from FGD participants to other smallholders not present, but whom the participants convinced to adopt Bt cotton.
- Actors or players in the innovation tree were also color-coded:
  - Black represents FGD smallholder participants.
  - Red represents company technicians and local technology extension stations.
  - Blue represents the dealers of seeds or other inputs.
  - Green represents smallholders who did not participate in the FGD, but who influenced other smallholder participants to adopt Bt cotton.
  - Gray represents smallholders who did not participate in the FGD, but who were influenced by those who had adopted Bt cotton.
- A grayed square indicates that the smallholders participated in the demo trial within the village.

Participants in the FGDs included the smallholders, the village cadres, technicians at the village level or from township technology extension stations, and seed or inputs dealers (if they exist) within a village. If the village is located close to the county seat or township, farmers buy seed there. The study by Chen et al. (2013) suggests there are no constraints on farmers accessing seed in the market. However, even though we witnessed the expansion of seed markets at all levels, administrative authorities have faced a storm of criticism on seeds not having the traits advertised. Furthermore, in some villages, if the smallholders have questions about production, they have to ask technicians outside the home village, as there is no local technician. On average, there are seven participants in FGDs, varying between 5 and 11 participants.

Findings from the Innovation Tree Exercises

As a supplement to the descriptive statistics, evidence from the FGDs better explain the variations in the adoption and diffusion process of Bt cotton across provinces. To present our findings from the FGDs, we categorize the each into two groups: one group is composed of smallholders in an FGD who started using biotechnology within three years of the initial commercial production in the province, such as those in Hebei province; the other group contains the remainder of the smallholders, such as those in Anhui province. Thus, there are two FGDs in Group 1 and two others in Group 2 in this study.

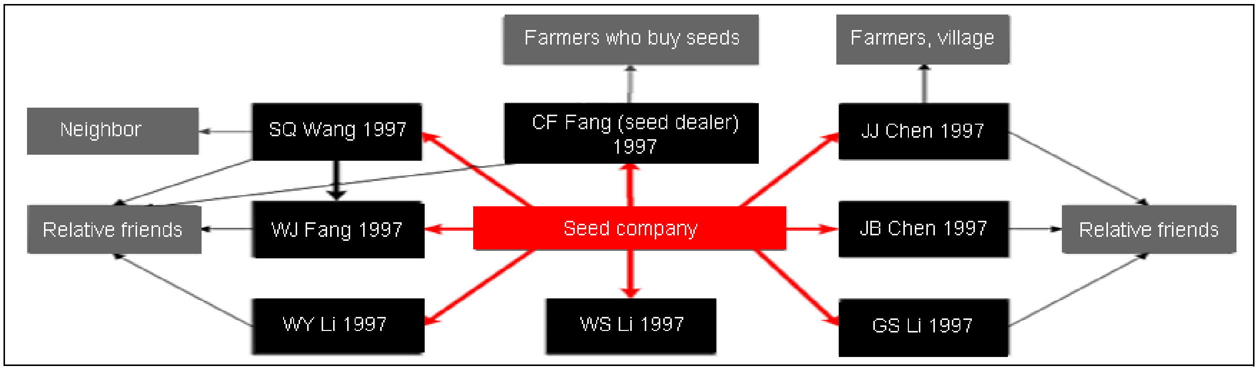

Figure 5. Uptake pathway of Bt cotton in Dalisi village, Hebei province.

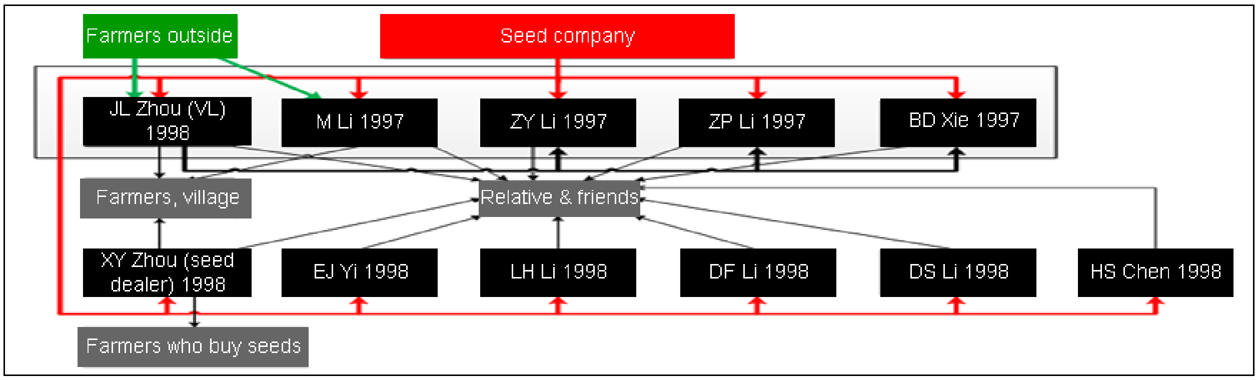

Figure 6. Uptake pathway of Bt cotton in Dongmuzuo village, Hebei province.

Dalisi Village, Hebei Province. The innovation tree exercise is consistent with the adoption rate at the village level obtained from national statistics. Both FGDs in the Hebei province (see Figures 5 and 6) explicitly show the rapid diffusion of Bt cotton (NC33B) in the villages. All of the smallholders had started to cultivate Bt cotton in one or two years after Bt cotton was offered in the market.

In 1996, technicians from a local cotton and fiber factory visited smallholders, and showed them demonstration fields in other townships. The smallholders were instructed on the different production aspects in the demonstration field, from transplanting the cotton crop to sowing seeds in nutrient blocks in a nursery to the harvest season in November. The participants of the training program were convinced by the better performance of Bt cotton in the field as compared with conventional cotton. Smallholders and village cadres also focused on the impact of Bt cotton on other cereal crops because in Hebei cotton is rotated with winter wheat and is in the same cultivating season as maize. They were also promised that Bt cotton with better adaptation to local agronomic conditions suppresses the bollworm population and will not influence the production of winter wheat.

The local cotton and fiber industry plays a greater role than just diffusing Bt cotton and guiding smallholders in the demonstration fields. In 1997, the industry signed a contract with the village cadres to collect all cotton after harvest. Since the risks existed, such as early frost and bollworm infestations that reduce yield, the industry compensates for the crop loss.[4] The local industry was responsible for supplying Bt cotton seeds to smallholders and guiding them during production, including spraying pesticide. All harvested cotton is sold to this industry, and smallholders were not allowed to save seeds for next year.

CF Fang, as the only seed seller, played an important role in diffusing Bt cotton in this village. In 1997, he cultivated Bt cotton together with his father, WJ Fang. As he benefited from the Bt cotton production on his family's farm, one year later he began to sell Bt cotton seed supplied by the local agent of Monsanto in the vil-

4. *Until now, few agricultural insurance programs have been implemented in rural China.*

lage. At the same time, he sold conventional cotton seeds. He learned more about the traits of Bt cotton and Bt cotton production, including the optimal quantity of pesticide to control cotton aphid and mirids. He acted as part-time technician, always sharing his knowledge about Bt cotton with the smallholders who stopped by his shop and helping them choose other inputs such as pesticide and chemical fertilizer.

In this village, we were not able to identify the leading farmers because the participants all started using Bt cotton in 1997. To reduce the potential risks, the Bt cotton was all cultivated on a small plot of land. These farmers also cultivated conventional cotton at the same time. Their answers can be summarized as follows. Even though the yield of conventional cotton was very low, the farmers are not familiar with the biotechnology. Thus, they preferred to reduce production risk through variety portfolio. Furthermore, after the first year, they were able to compare the performance of Bt cotton with conventional cotton under almost the same agronomic conditions and exposure to risks such as bollworm infestations and frost.

The rapid diffusion of Bt cotton in this village happened because all participants were anxious to share biotechnology with others. They shared information with fellow farmers in the village, as well as among neighbors and relatives outside the local community. They said some fellow farmers or relatives came to their fields to observe the production as they themselves had done one year before on the demonstration field. The area occupied by Bt cotton doubled in 1998 and kept growing to more than two-thirds of total area in this village until 2006.

Dongmuzuo Village, Hebei Province. The introduction of Bt cotton was unique in this village. After the introduction of the household responsibility system, land-use rights were vested in households, subject to an equalized framework, but smallholders were requested to fulfill quotas tied to the land (Brandt, Huang, Li, & Rozelle, 2002; Huang, Wang, & Rozelle, 2013; Liu, Carter, & Yao, 1998). For a long time, the quota could only be paid in kind, but cash was accepted later (Sicular, 1988). In this village, cotton is an important crop under the quota system. However, owing to serious pest infestations, especially bollworm, the smallholders stopped cultivating cotton despite that this meant fulfilling the quota in cash, even though much of their farming experience was in cotton production. At that time, smallholders in other villages who suffered from bollworm infestations still cultivated conventional cotton before Bt cotton in their fields.

The source of Bt cotton information was the local seed company. Guided by the local seed company, one village cadre, JL Zhao and farmer M Li, were very impressed by the yield of Bt cotton on the demo field and were informed by other smallholders who had worked on the demo field about the major advantages of Bt cotton versus conventional cotton.

Subsequently, the diffusion pathway of Bt cotton was mainly promoted by village cadres under the constraint of the land equal-distribution system. In 1997, village cadres representing some of the farmers signed a breeding seed contract with the local seed company. Under the terms of contract, a 10-ha area was used to breed Bt cotton seed (we define this as a trial field, for clarity). The seed company would buy all Bt cotton seed at a certain price. Some of the other terms concerned compensation for risks and farmers' saving seeds. Under the land distribution system at the time, this trial field had been distributed to some of the farmers in this village. In order to accomplish the breeding contract, village cadres needed to convince all households who owned some plots on the trial field to agree to this contract because farmers are free to organize their own agricultural production. The leading farmers were those who owned one or more plots of land on this trial field and who started to cultivate Bt cotton in 1997, together with the village cadres, including JL Zhao.

The participants in this village took two years to adopt Bt cotton, and the appearance of Bt cotton contributed significantly to the recovery of cotton production. Following the leading farmers, other smallholders in the FGDs started to cultivate Bt cotton after stopping conventional cotton production in the early 1990s. They were motivated by the good performance of Bt cotton in the trial field and were anxious to adopt it after being informed about the benefits and costs by the leading farmers within this village. We also asked if they cultivated conventional cotton at the same time. All of them said they would not cultivate cotton if Bt cotton was not offered in the market. They would not take the risk of crop loss in the case of serious pest infestation. Furthermore, they were afraid that the bollworm on conventional cotton would have a negative impact on Bt cotton production, suggesting that smallholders still have limited knowledge about biotechnology. Thus, in the beginning, smallholders only cultivated Bt cotton on small plots of land. This is why the share of cotton area to total area was still low, at only 8% in 1997 and 17% in 1998, much less than those in other counties.

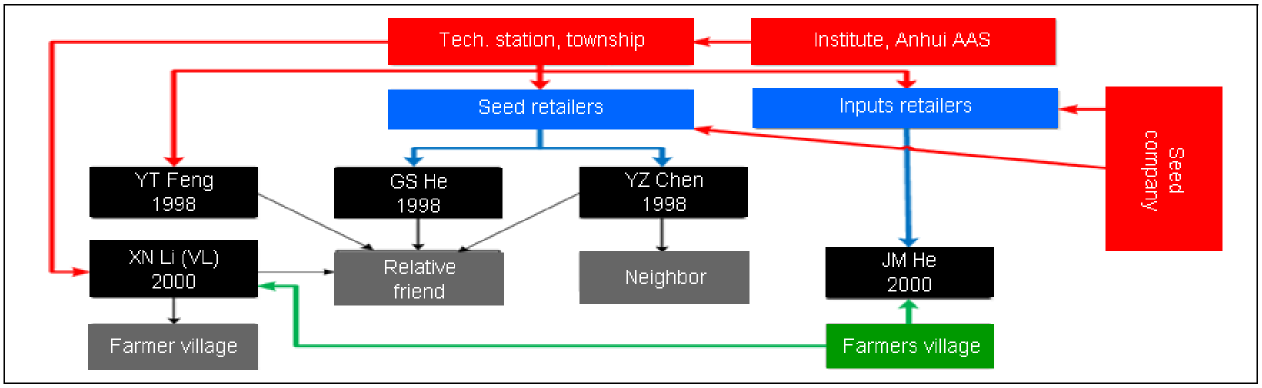

Figure 7. Uptake pathway of Bt cotton in Longtan village, Anhui province.

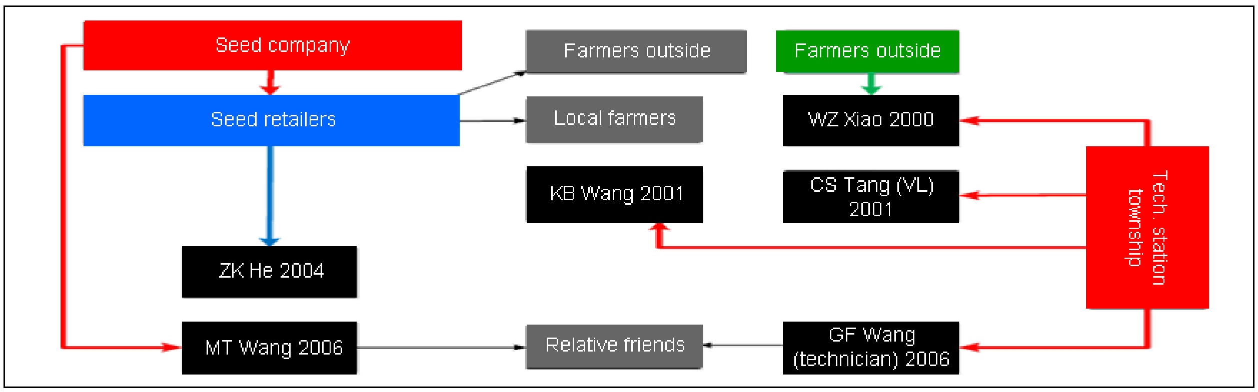

Figure 8. Uptake pathway of Bt cotton in Jiguan village, Anhui province.

Seed sellers play an important role in the diffusion process. They began cultivating Bt cotton and selling Bt cotton seed in 1998. They also extended this biotechnology to farmers, local and non-local, through the marketing of seed and other inputs.

Longtan Village, Anhui Province. Bt cotton production in Anhui dated back to 1997. However, unlike Hebei, none of the farmers in the two villages adopted Bt cotton in the first year for two reasons (see Figures 7 and 8). First, farmers were not able to obtain Bt cotton seed owing to the limited supply in the market. Bt cotton seed was only supplied by institutes; it was not yet available in the market. Second, without confirming the promised traits of Bt cotton, farmers would not risk cultivating Bt cotton, as the bollworm infestation was just as serious as those in Hebei province. After the collapse of the technology extension system at the township level, farmers were never shown the demo field. Furthermore, at that time, the market strategies of the seed companies in these two counties was limited.[5]

Again, the availability of Bt cotton seed made the adoption of Bt cotton possible. The source of Bt cotton seed to the input sellers at the village was the extension station at the township or the seed company at the county seat. In 1998, the leading farmers who were willing to cultivate Bt cotton bought the seed from seed sellers within a village after they were informed of the traits by the sellers. Unlike village cadres in Hebei province, village cadres in this village were neutral to the diffusion of Bt cotton. They were not against the adoption of leading farmers on their plots of land in 1998, but they would not act as the leading farmers. The village cadre in the FGDs only followed the leading farmers and responded similarly in adopting Bt cotton in 2000, when the adaptation rate increased to 50%.

Jiguan Village, Anhui Province. The diffusion pathway obtained from this village indicated that it took a decade before all participants had adopted Bt cotton after the initial commercial release in 1997. The following four reasons could explain the slow adoption. First, the technology extension station only organized one workshop to introduce Bt cotton in this village in 1997.

5. *In the late 1990s and early 2000s, the size of seed firm is very small, with only few staff to sell seeds locally.*

Without the help of the village cadres, few farmers joined the workshop and few understood the advantage of Bt cotton over conventional cotton. Second, Bt cotton seed can only be supplied through the chain of technology extension stations, and the supply of Bt cotton seed was not met by demand in this county. Since 2001, after three varieties developed by Monsanto were available in the market, the short supply of Bt cotton seeds was addressed. Third, the incentive for adopting Bt cotton was dampened by anecdotes. When news of Bt cotton was announced, farmers mistakenly believed that when a gene is modified, the seed is a poison. This anecdote spread rapidly among smallholders, with some cases fabricated. Furthermore, the local cotton and fiber industry refused to collect Bt cotton. Finally, the price of Bt cotton seed was much higher than that of conventional cotton. Without the calculation on the costs and benefits of Bt cotton and conventional cotton, farmers were not willing to cultivate Bt cotton.

Furthermore, there is no obvious diffusion pathway among the participants, even though both village cadre and village technician were involved in the innovation tree exercise. Smallholder WZ Xiao, who cultivated earlier than other participants, was informed about Bt cotton from farmers in the neighboring villages and from the workshop organized by technology extension station in other villages. One year later, village cadre CS Tang and farmer KB Wang learned from a similar workshop and started to cultivate Bt cotton. After 2000, the offering of varieties was accelerated and seed sellers in the village were able to obtain Bt cotton seed from the upper seed supplier, like a seed company at the county level. After a decade of almost 100% adoption rate of Bt cotton, the technicians at the village level started to cultivate Bt cotton. If a technician does not understand the biotechnology, despite being trained, his role in diffusing biotechnology within a community is very limited.

During the group discussion, farmers told us that their decision on whether to adopt Bt cotton is influenced by the attitude of village cadres and technicians. The attitude of village cadres to Bt cotton was regarded as being neutral because they did not help the technology extension station to organize the training workshop within the village. However, they did not say no either. After they attended the workshop, they themselves did not cultivate Bt cotton. Until 2001, the village cadre cultivated Bt cotton, but he did not share his experiences with others. The attitudes of village cadres and technicians made farmers doubt the information on Bt cotton from other sources. Without the training workshops every year, the diffusion of Bt cotton would take a longer amount of time.

Summary from FGDs

The findings from the FGDs explicitly show that the characteristics of Bt cotton, including the improved adaptation to local agronomic conditions, among other benefits, result in the rapid diffusion of Bt cotton in China. Without good performance, smallholders would not replace conventional cotton with Bt cotton, given the risk of serious pest infestation. Smallholders will not buy a specific seed without the promised benefit after the careful cost and benefit calculation. If the plots cultivated by leading farmers are regarded as demo plots, smallholders followed leading farmers by observing the production on these plots. Smallholders went to the plots of leading smallholders during each of the planting seasons, for example, the season for pruning, blossom, and harvest.

In the first stage of Bt cotton diffusion, both seed companies and the technology developers (e.g., research institutes or biotech companies) played an important role in farmers' use of Bt cotton. Leading domestic seed companies, working with technology developers, sold Bt cotton seeds to some of the initial adopters. At the same time, local public agricultural extension technology extension staff (or technicians) and leading farmers were invited to visit Bt cotton trial fields or demonstration fields to facilitate the initial adoption of Bt cotton by farmers. In some villages, training workshops or visits to Bt cotton field trials, coordinated by village leaders, were provided to farmers who later became the first adopters of Bt cotton. Some village leaders also coordinated the Bt cotton seed generation and set up the seed purchasing contracts with the seed company. This helped their villagers become first adopters and facilitated the expansion of Bt cotton in the villages. With the outstanding performance of Bt cotton by the first adopters, other farmers in the same village rapidly followed suit. Generally, farmers visited the Bt cotton fields of the first adopters and learned the advantages of the technology. The followers also learned and adopted Bt cotton from their neighbors, other farmers inside or outside their villages, or the hometown of their spouse.

However, it is worth noting that when Bt cotton was first released, there were serious constraints on its adoption. Many farmers wanted to plant Bt cotton, but could not obtain the seeds from the suppliers. Given their limited knowledge about biotechnology, some farmers also delayed their adoption.

This study has several policy implications. To facilitate GM technology diffusion to farmers, seed companies, technology developers, local village leaders, and first adopters of technologies can play important roles. Local technology extension services and training are also critical in disseminating appropriate information and knowledge to farmers so that they can fully benefit from the new technology. With regard to the perspective of GM technology, some smallholders mentioned they know all the agricultural practices in planting Bt cotton. Others are eager to understand when and how much pesticide and fertilizer to use.

Conclusion

China is one of the first countries to have commercialized GM crops. Bt cotton was produced in 1997 and was then rapidly adopted by farmers. Our survey shows that the adoption rate of Bt cotton reached nearly 100% by the early 2000s in the Huang-Huai-Hai region, a major cotton-production region in China. Bt cotton is well documented as a success story of biotechnology adoption in China.

The introduction of Bt cotton helped millions of small farmers recover their cotton production in the late 1990s and early 2000s. Even though China has a long history of cultivating cotton, the outbreak of the cotton bollworm in the mid-1990s caused the cotton area to shrink. With the availability of Bt cotton for farmers, in the majority of sampled counties, the share of cotton area to total area increased as Bt cotton became more widespread.

Bt cotton technology is neutral technology that benefited all farmers. Farmers in Huang-Huai-Hai region were all smallholders with an average cultivated land area of less than one hectare. As all cotton farmers are smallholders, all gained significantly by adopting Bt cotton. Major benefits of planting Bt cotton include a reduction in insecticide use, mitigating yield loss from bollworm attacks (or increasing yield), and saving labor inputs in cotton fields. As cotton farmers tend to be relatively poor, Bt cotton significantly improved their income and livelihood. However, there was spatial pattern of Bt cotton production evolution. It started in the Huang-Huai-Hai region, followed by the Yangtze River cotton production region. This spatial evolution was closely correlated with serious local pest problems (e.g., bollworm), the nature of biotech crops, and biosafety regulation.

Our analyses show that in the first stage of Bt cotton diffusion, both seed companies and the technology developers played important roles in farmers' use of Bt cotton. Seed companies and technology developers (e.g., research institutes or biotech companies) conducted Bt cotton field trials in cotton-production villages where farmers often became the first adopters of Bt cotton varieties. Technology developers also arranged Bt cotton field demonstrations in major cotton production regions, which helped the early adopters' to understand the technology.

At the same time, local public agricultural extension technology extension staff (or technicians) and leading farmers were important facilitators in the initial stage of Bt cotton adoption. For example, some local extension technicians invited farmers to visit Bt cotton trial fields or demonstration fields of technology developers. In some villages, coordinated by village leaders, training workshops on Bt cotton or visiting Bt-cotton field trials were provided for farmers who became the first adopters of Bt cotton. Some village leaders also coordinated the Bt-cotton seed generation and set up the seed purchasing contract with the local seed company. This helped their villagers to become the first adopters and facilitated the future expansion of Bt cotton in the villages.

With the outstanding performance of Bt cotton by the first adopters, the other farmers in the same village rapidly followed suit. Generally, farmers visited the Bt cotton fields of the first adopters and learned the advantages of the technology. The followers also learned and adopted Bt cotton from their neighbors, other farmers inside or outside their villages, or the hometown of their spouse. However, it is worth noting that when Bt cotton was first released, there were serious constraints on its adoption. Many farmers wanted to plant Bt cotton, but the supply of Bt cotton seed did not meet their demand. Since most Bt cotton varieties were conventional (or not hybrid), lack of seed availability was overcome by many farmers by using their own saved seeds or getting seeds from other farmers who planted Bt cotton in the previous year. The availability of Bt cotton seed in each new province was also subjected to biosafety regulations because the approval of Bt cotton in China is case-by-case and region-by-region. In addition, our study showed that some farmers delayed adopting Bt cotton because of their limited knowledge about biotechnology.

The results of this study have several policy implications. To facilitate the rapid diffusion of GM technology to farmers, both public and private sectors can play important roles. First, the ability of seed companies to generate enough seed for the market after the approval of a biotech crop affects the scale of initial adoption or the number of farmers who can plant the new crop. A strong seed industry is critical to diffusing new technology. Second, technology developers from either public research institutions or biotech companies are important facilitators in the initial diffusion of biotechnology. Through field trials and demonstrations, nearby farmers can learn the advantages of the technology and become the initial beneficiaries. This will stimulate other farmers to follow. Third, having a good local technology extension and training service is critical to disseminating appropriate information and knowledge to farmers so that they can fully benefit from the new technology. Fourth, engaging with local village leaders to arrange purchases of biotech crop seed helps farmers, particularly smallholders, to access the new technology. Fifth, similar to other technology diffusion, improving the social network of farmers can facilitate the rapid adoption and pathways of Bt cotton diffusion. Lastly, to accelerate the diffusion of new technology, China may need to revisit its current case-by-case and region-by-region biosafety regulation approach. The event-based biosafety regulations widely used in the United States, EU, and other countries may help China's future adoption of GM technology.

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Appendix: Group questions for the innovation tree activity

The following will be asked after all smallholders have shared the month and year of adoption, who informed him/her first, who convinced him/her, and who he/she convinced:

1. Did you hesitate at first to adopt? If yes, why so? What other factors made you apprehensive about adopting the crop? If no, why so?
2. What compelling statements (e.g., phrases, assurance) did you receive or hear from people convincing you to adopt Bt cotton and those discouraging you?
3. How did the leaders in your village react to the introduction of Bt cotton among the local smallholders? Were they fearful, hopeful, or disinterested about it being cultivated in your village? Why so?
4. What did the village cadres do to help the adopters become successful in growing Bt cotton? Please elaborate on the important roles that they play in the adoption of Bt cotton by smallholders and the increase in number of adopters in the village.
5. What were the most crucial chunks of information shared to you by the following that contributed to the success of your Bt cotton production endeavor: fellow smallholders, relatives, traders, seed technicians, MAO technicians, and others? How did the information help you?
6. Among the benefits you have had from growing Bt cotton, what made a considerable impact on your life and your family's? Why?
7. What benefits did your village, in general, get from growing Bt cotton?
8. What else do you want to know about Bt cotton? Why?
9. How do you see yourself as a biotech smallholder in the next five years?
10. What role must the government play in promoting Bt cotton?