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Variety Market Development: A Bt Cotton Cropping Factor and Constraint in China

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In China, Bt-cotton varieties have been marketed since 1997 to help control attacks of some cotton pests, notably *Helicoverpa armigera*. It is estimated that Bt-cotton is currently grown on about 70% of the total Chinese cotton-growing area. Most studies have explained this broad distribution by the specific advantages of Bt-cotton, particularly the reduction in pesticide use but this has been questioned by some recent papers, which also raised the issue of seed prices. In our study, which is based on datasets seldom used in earlier analyses, we argue that Bt-cotton use in China has been influenced by the development of the cotton variety market. Bt-cotton adoption has benefited from the development of the variety market facilitated by a favorable legal framework since the mid-1990s. Yet, quality uncertainties and high seed prices threaten the profitability and continued use of Bt-cotton as well as development of the variety market. A quality seed subsidy policy was launched in 2007 to rectify the disorder in the variety and seed market, but the effectiveness of this regulation measure is debatable.

Key words: Bt-cotton, China, competition, intellectual property rights, regulation, seed market.

Introduction

In China, Bt-cotton varieties have been marketed since 1997 to help control attacks of some cotton pests, notably *Helicoverpa armigera*. It is estimated that Bt-cotton is currently grown on about 70% of the total Chinese cotton-growing area (James, 2008).

Most studies have explained this broad adoption by the specific advantages of Bt-cotton achieved through reductions in pesticide use (Bennett, Morse, & Ismael, 2006; Huang, Hu, Rozelle, Qiao, & Pray, 2002; Pray, Huang, Hu, & Rozelle, 2002). A few studies have assessed the issue of lack of variety and seed quality with respect to Bt-cotton performance (Bennett, Ismael, & Morse, 2005; Crost, Shankar, Bennett, & Morse, 2007) and to farmers' practices in controlling cotton pests (Pemsl & Waibel, 2007), but no studies have investigated the relationship between Bt-cotton diffusion and variety market development, not to mention its impact on the Bt-cotton adoption in the long run.

Indeed, the Chinese success story in using Bt-cotton has been recently questioned (Wang, Just, & Pinstrup-Andersen, 2006, 2008). Reportedly, the profitability of the technology has been notably hampered by the need for more chemical control of alternative pests and by the substantial increase in Bt-cotton seed prices. As we explain here, seed price increases are connected to the nature of competition in the cotton variety market development, which is curious because China is one of the few countries where competition in supplying Bt-cotton varieties is quite strong. Specifically, there are two sources of Bt-genes and three types of Bt-cotton variety: varieties integrating the Monsanto *Cry1Ac* gene, varieties with the Chinese Bt gene,[1] and varieties combining the Chinese Bt gene with the CpTi (cowpea trypsin inhibitor) protease gene.

In this article, we analyze the recent development of the cotton variety market in China. We argue that Bt-cotton use in China is closely related to this market development. On the one hand, Bt-cotton adoption has benefited from the development of the variety market facilitated by a favorable legal framework since the mid-1990s. On the other hand, harsh competition in the development of cotton varieties is responsible for quality uncertainties and possibly high seed prices and, hence, it is now threatening to stall the variety market development while also possibly reducing the profitability of Bt-cotton use.

The next section reviews some relevant details of Chinese cotton geographic distribution, cultivation techniques, and associated breeding options for new cotton varieties. Then, the article outlines the institutional shift that has promoted the development of the variety and seed sector. The following section discusses the phe-

1. *Note that the so-called "Chinese Bt gene" is Cry1A, constructed by the Biotechnology Research Institute, Chinese Academy of Agricultural Sciences (Guo & Cui, 2004).*

nomenon of widespread diffusion of Bt cotton and then highlights the relationship between Bt-cotton diffusion and the development of the variety market. Next, we discuss the influence of market competition on seed quality and prices, as well as the Chinese government's attempt to regulate the variety and seed market. Various data sources are tapped and as such they are introduced and discussed throughout the article.

Characteristics of Cotton Production in China

In China, cotton has been produced in three main regions with distinct settings with respect to pest pressure and agronomic constraints for cotton growing. The Yellow River Valley (YeRV) is the main traditional cotton-producing zone. This cotton zone essentially consists of the Hebei, Henan, and Shandong provinces (hereafter referred to as the Yellow Three) where strong bollworm resistance to insecticides arose in 1992/1993 and where Bt-cotton was first released in 1997. In north western China production is concentrated in the Xinjiang province, which is the leading province for cotton production in China. In this arid zone, pest pressure is low and there should be limited interest in using Bt-cotton. The Yangtze River Valley (YaRV) ranks third in cotton production although it encompasses more provinces. Pest pressure is lower than in YeRV, and pest resistance to insecticides was reported first only in 1998. An annual two-crop rotation is common, where cotton follows a winter cereal, and there is commonly some risk that the cotton crop could be partly or totally destroyed by early frost.

Chinese scientists have developed a unique transplanting technique that prevents cotton crop destruction by early frost in YaRV and its adoption has been favored by hybrid varieties. This is a rather sophisticated technique consisting of sowing seeds in nutrient blocks in a nursery and then transplanting them in the field right after the winter cereal crop residue is burnt (Fok & Xu, 2007). Farmers are attracted by the higher yield and lower frost risk but it is labor intensive to make and transplant the nutrient blocks. This labor intensiveness is proportional to the cotton-stand density in the field. The stand density can be reduced by planting more vigorous plants such as hybrid varieties (30,000 plants/ha instead of 45,000 plants/ha). Although research on hybrids was launched in the 1960s, the expansion of their use dates back to the late 1990s, essentially in regions where cotton transplanting is common (see Table 5).

Before the commercial release of Bt cotton, seeds were distributed in a rather outdated way. The National Cotton and Jute Company in charge of marketing and ginning farmers' cotton production also distributed fuzzed seeds in large packages, sometimes without any indication of the variety name. Many farmers were suspicious of the seed and the variety quality and preferred to use and exchange seeds that they themselves had produced.

Institutional Changes for Variety and Seed Market Development

The development of the variety and seed market benefitted from a remarkable change in the institutional framework linked to the application of the Seed Law (SL) and of the Plant Variety Protection Act (PVPA). These laws are briefly introduced here, but Fok and Xu (2009) provided a detailed account and analyzed them with reference to other emerging countries (Fok & Xu, 2010).

The first version of the SL was issued in December 1989 and was revised several times since. The PVPA was issued in 1997 and its application was decreed in 1999. New rules regarding variety and seed markets actually began being applied around 2000.

The development of new cotton varieties and seed markets has clearly benefited from the adoption of the SL and PVPA. This legislation was drawn up for the main crops in China—especially cotton—to promote the development of new varieties and the supply of quality seeds to farmers. All organizations, particularly public scientific and technical institutions, were encouraged to commit to seed breeding, production, and distribution (Article 6, Article 21, and Article 28 of SL) by acknowledging that proprietary rights must be fairly compensated financially (Article 12 of SL) when seeds were marketed.

The marketing of varieties without clear proprietary rights is now prohibited (PVPA, Article 6). Breeders do not need the consent of the owner of a given variety to include it in their breeding programs (PVPA, Article 10), regardless of the variety's genetically modified (GM) or non-GM status. The same article ensures farmers' right to use the seeds that they themselves produce for their own use or even for selling to other farmers (SL, Article 27). Farmers' free choice of seeds is strongly acknowledged. No person or institution can withdraw these farmers' rights (Article 39).

The new institutional framework has had a clear impact on seed supply and demand. The institutional framework guarantees farmers' freedom to save their cotton varieties and seeds. Farmers can easily produce their own seeds via self-pollinated cotton plants. Seed saving is also facilitated by the existence of small-scale ginning shops and the small quantities of seeds needed by the average farmer for growing the typical one-third of a hectare. In Hebei province it was found that up to 55% of cotton growers used held-back seeds partially or totally in 2002 and 2003 (Fok, Liang, Wang, & Wu, 2005), though this phenomenon is reported to be declining (Liu, 2006).

The institutional protection of farmers' rights to use their own seeds potentially tends to reduce the demand for commercial seeds, to the detriment of variety owners and seed distributors. For seed firms, it could therefore be a more profitable commercial strategy to offer hybrid varieties, whose seeds must be purchased anew every year, at least where their improved profitability is acknowledged by farmers, as in the case of transplanting cotton. This is of further interest when it's considered how easy and fast it is (1 year vs. 8 years on average) to create a new hybrid as compared to a conventional variety. Technically speaking, it is just as easy to breed a Bt-cotton hybrid as well because a Bt cotton variety can be crossed with another variety carrying sought-after agricultural characteristics. Additionally, there is evidence of a heterosis effect on higher Bt-gene expression (Dong, Li, Tang, Li, & Zhang, 2007). From an economic viewpoint, creating new Bt-cotton varieties is also not hampered by the cost of access to Bt technology. Until recently, cotton breeders paid the technology fee once and for all when registering new varieties (certificates confirming the Bt nature of a new variety are issued by the proprietor organization of the Chinese Bt gene). According to the breeding companies we interviewed, the certificate fee decreased from €30,000 in the late 1990s to about €3,000 in 2005. These payment conditions have recently evolved, but these changes occurred beyond the period analyzed in this article.

Bt Cotton Diffusion

Data Used

This section is based on two data series which are more or less open to public access and that the authors reconstituted and formatted. The first series is now available for easy public access and pertains to data on cotton area and production at whole country, province, and district levels. These official data are contained in the Agricultural Year Books of the Chinese Ministry of Agriculture. The second series is issued by the National Agro-Technical Extension and Service Centre (NATESC), a department of the Ministry of Agriculture, in a yearly report on areas where the main cultivars of major crops, including cotton, are grown. In its data collection, NATESC staff only recorded data for cultivars surpassing a threshold cropping area whose value has fluctuated over time (between 667 and 6,667 ha).[2] We will refer to these data as "NATESC cultivar area data."

The official nature (Bt or not, hybrid or not) of the varieties, declared at the time of variety registration has also been integrated into the database, but the accuracy of such information was checked because of possible false declarations. Bt-cotton varieties could have been declared as non-Bt varieties so as to sidestep payment of royalties to the Chinese Bt-gene owner. Cases of non-Bt varieties marketed as Bt have also been reported (Pray, Courtmanche, & Govindasamy, 2001). The verification was possible thanks to one of the authors' expertise and the assistance he obtained from fellow breeders nationwide. Through this process, out of 262 varieties of officially non-Bt cotton for the period of 1997-2007, 24 were confirmed to be Bt cotton. The data analysis will be presented according to the official and confirmed Bt nature of the varieties.

The NATESC cultivar area data are used extensively in this article to illustrate the overall dynamics of the variety market. While the administrative processes used in the collection of the article is not perfect, we believe that any data limitation does not affect the basic conclusions drawn about the dynamics of the variety market.

Widespread Bt-Cotton Use, Albeit with Variation

Cotton is produced in 17 Chinese provinces or municipalities, but this production is substantial in only eight provinces, principally along the Yellow River Valley (notably the Yellow Three), the Yangtze River Valley (mainly Jiangsu, Anhui, Hubei, and Hunan Provinces) and in Xinjiang province. In this article, results were analyzed for this group of provinces and for the Chinese production overall.

The adoption of Bt-cotton has helped re-launch production. The impact of Bt-cotton use on Chinese cotton production patterns is clearly shown in Figure 1, which presents production trends over the past 25 years. We made a distinction between the whole of China and the Yellow Three with respect to production and area.

2. *Corresponding to 10,000 and 100,000 mu (1 ha = 15 mu)*

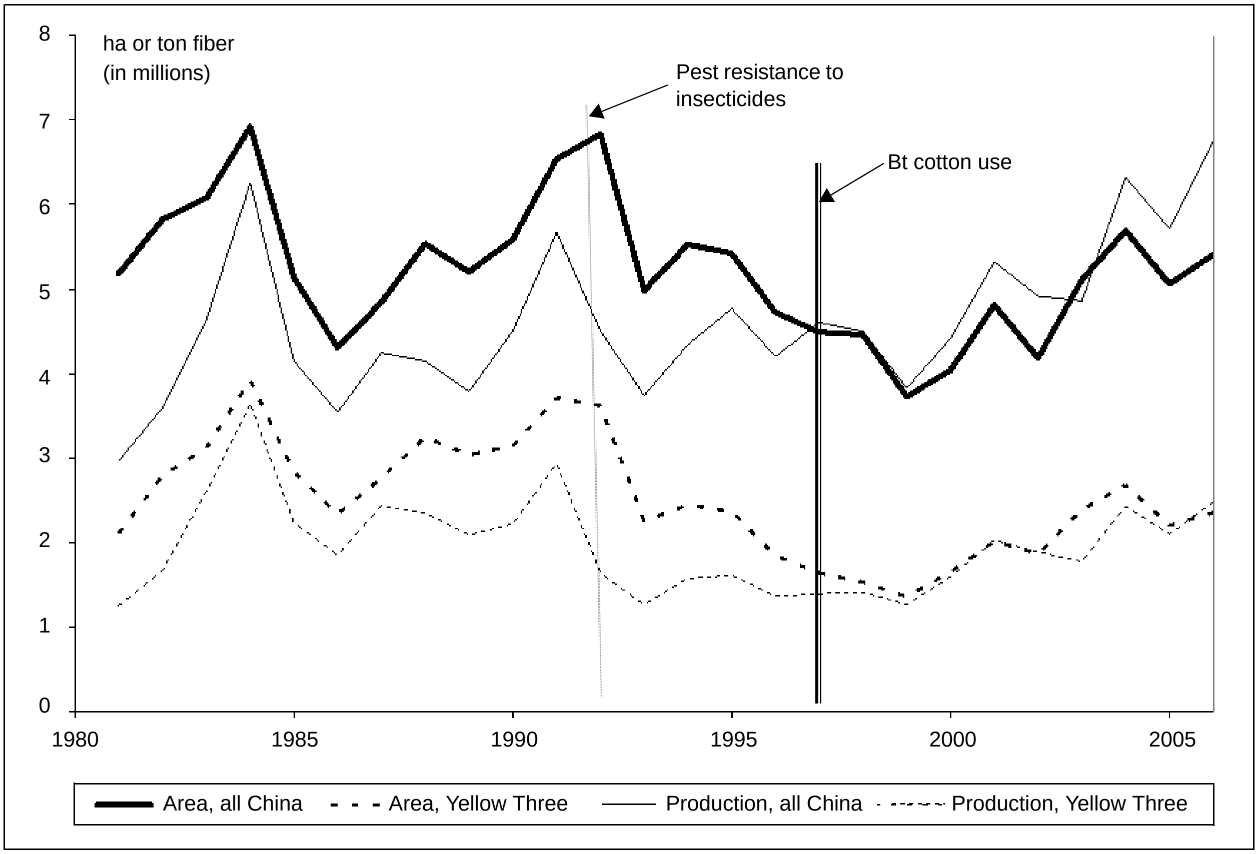

Figure 1. Evolution of cotton area in China and in the "Yellow Three."
Note: from data of Agricultural Year Books, Ministry of Agriculture, China

When China reached its record production in the 1984 cropping season, the Yellow Three accounted for more than half of total production. The production in this region collapsed with the onset of bollworm pesticide-resistance in 1992-1993, however. This production declined and then stagnated in line with changes in the size of the cotton-producing area, until the introduction of Bt cotton in 1997, which contributed to a real rebirth in cotton production. This positive impact of Bt cotton has nevertheless had limitations; the new decline since 2005 indicates that other limiting factors, mostly economic in nature, were also crucial. The analysis of these factors goes beyond the scope of this article.

There were variations in the share of Bt-cotton throughout the production area in China. The widespread use of Bt-cotton in China resulted from the introduction of Monsanto varieties that were tested in 1995 and 1996 and obtained special permission for commercial release in 1997 even before PVPA was drafted in October 1997. Prior to this introduction of US varieties, China also achieved a first generation of Bt-cotton varieties through the National Cotton Research Centre (located in AnYang, Henan province); this explains why there was some Bt-cotton area recorded in 1996. Table 1 shows the Bt-cotton adoption patterns throughout the main cotton provinces, with some discrepancies between the Bt-cotton coverage according to the official and the actual Bt-nature of the varieties.

Referring to the actual Bt nature of varieties, about 50% of coverage was achieved at the national level six years after the commercial release of Bt cotton. That coverage seems to have stagnated at around 70% since 2004. This is consistent with the findings of James (2008). The rapidity and extent of Bt-cotton diffusion were even more dramatic in the Yellow Three. In the other provinces, the maximum Bt-cotton share has fluctuated from 80% to 95% (Anhui, Jiangsu, and Hunan). The pattern in Hubei Province was somewhat unique, with a rather low coverage (37%). In Xinjiang Province, Bt-cotton adoption began more recently and remained at a low level until 2005, though this was still surprising given the low level of bollworm pressure.

The marketing of Monsanto Bt varieties has contributed to the rapid and widespread adoption of Bt cotton.

Table 1. Evolutions of the Bt share in cotton area and of the share of US Bt varieties (%).

Main cotton provinces		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Anhui	**Real Bt status**			2.4	8.4	23.2	57.5	41.6	69.2	89.9	97.4	55.0
	Official Bt status			2.4	8.4	23.2	57.5	41.6	63.5	83.5	95.1	44.7
	US share of Bt area					58.8	64.9	25.6	16.8	0.0	0.0	9.6
Shandong	**Real Bt status**			12.6	74.4	90.2	100.0	100.0	98.1	100.0	100.0	100.0
	Official Bt status			12.6	74.4	90.2	100.0	97.8	92.6	91.8	94.0	96.4
	US share of Bt area			49.2	68.5	68.3	75.9	56.3	53.6	22.1	12.5	8.0
Jiangsu	**Real Bt status**				3.3	6.6	9.7	34.8	60.2	80.4	78.1	80.6
	Official Bt status				3.3	6.6	9.7	34.8	60.2	80.4	70.2	75.5
	US share of Bt area							23.7	4.7	0.0	0.0	0.0
Hebei	**Real Bt status**		22.8	70.7	90.3	100.0	94.7	95.4	98.3	100.0	100.0	97.0
	Official Bt status		3.1	59.5	90.3	100.0	91.4	86.4	68.7	70.2	65.7	44.7
	US share of Bt area			100.0	94.2	74.9	79.1	77.1	76.9	61.1	61.1	31.2
Henan	**Real Bt status**	1.9	1.1	1.9	19.0	38.7	70.3	62.3	78.0	91.7	83.1	82.9
	Official Bt status	1.9	1.1	1.9	19.0	38.7	70.3	62.3	65.8	74.5	78.3	76.5
	US share of Bt area					13.3	57.3	53.1	32.6	21.9	15.4	8.4
Hubei	**Real Bt status**					27.2	25.1	29.5	33.3	33.3	29.7	37.2
	Official Bt status					27.2	25.1	29.5	33.3	33.3	29.7	20.8
	US share of Bt area					9.0	0.0	0.0	0.0	0.0	0.0	0.0
Hunan	**Real Bt status**							8.8	49.0	65.6	79.8	82.4
	Official Bt status							8.8	37.9	59.9	79.8	70.6
	US share of Bt area											
Xinjiang	**Real Bt status**						1.6	0.0	2.4	3.8	5.0	19.0
	Official Bt status						1.6	0.0	2.4	2.1	2.6	11.2
	US share of Bt area								34.8	0.0	0.0	0.0
China	**Real Bt status**	0.5	2.9	7.6	21.0	39.7	45.7	49.1	64.0	69.4	70.9	69.7
	Official Bt status	0.4	0.9	6.3	20.2	39.8	45.1	48.5	56.0	59.1	61.8	55.1
	US share of Bt area*			71.4	61.6	52.5	62.1	52.3	37.3	21.1	15.7	7.4
	Bt share, ISAAA**		0.8	5.9	17.6	30.1	45.2	50.2	54.8	65.0	65.2	64.7

Note: calculation from data of NATESC and after control of the real Bt nature of varieties.

** Ratio calculated by using the real Bt status of the cotton varieties*

*** Reconstituted from ISAAA reports, based from indication of Bt-cotton area and total area as indicated by the Chinese Ministry of Agriculture*

Several varieties were marketed, but DP33B and then DP99B were, successively, by far the most successful Monsanto varieties. Nationally, the Monsanto share in Bt-cotton areas stood at 72% in 1998, but it has been steadily declining to the present level of less than 8%. Provincially, the maximum share was far higher in the Yellow Three (also in neighboring Anhui province). Elsewhere, Monsanto varieties never succeeded in penetrating the cotton seed market. In all provinces, the market share of Monsanto varieties has been declining at the same rate. The notion of area share is more appropriate because most farmers adopting Monsanto varieties only partially purchase commercial seeds.

Bt Cotton and Variety Market Development

Data Used

In this section, in addition to the NATESC cultivar area data, we tapped another data source to assess variety market trends. This data series was developed for the implementation of SL and PVPA. To our knowledge, this data series has seldom been used.

According to SL and PVPA, the geographical cultivar marketing scope is delimited according to the variety registration process. Varieties must comply with more stringent procedures when marketing over the whole national territory. The Ministry of Agriculture is

Table 2. Evolution of the number of varieties with regard to the area threshold for recording.

	A	B	C	D	E
Provinces	No. varieties with area recorded	No. varieties with area over 6,667 ha	Total area of all varieties used* (ha)	Mean area of all varieties used* (ha)	Mean area*/year (ha)
			Period 1990-1999		
Anhui	83	83	2,960,636	35,670	3,567
Shandong	132	132	7,933,956	60,106	6,010
Xinjiang	109	109	6,117,295	56,122	5,612
Jiangsu	86	86	4,578,637	53,240	5,323
Hebei	117	117	4,945,298	42,268	4,226
Henan	150	150	8,923,951	59,493	5,949
Hubei	81	81	4,013,973	49,555	4,955
Hunan	37	37	1,364,654	36,883	3,688
All China	199	199	44,423,680	223,235	22,323
			Period 2000-2006		
Anhui	144	79	2,202,756	15,297	2,185
Shandong	146	106	5,360,531	36,716	5,245
Xinjiang	190	137	5,973,143	31,438	4,491
Jiangsu	117	77	1,999,590	17,091	2,441
Hebei	76	62	3,692,185	48,581	6,940
Henan	233	133	5,111,387	21,937	3,133
Hubei	116	92	2,126,624	18,333	2,618
Hunan	75	24	859,529	11,460	1,637
All China	372	203	28,854,401	77,566	11,080

Note: from NATESC cultivar area data
** varieties recorded with area superior to thresholds whose values have fluctuated from 667 to 6,667 ha (or 10,000 to 100,000 mu)*

in charge of coordinating the multi-location varietal experiment for national registration, and it has set up a specific website through which we reconstructed data series on cultivars submitted from 1999 to 2007. We checked the nature of the breeding organizations and categorized them according to their status into private companies, research institutes, and universities. These data is referred to here as information from the "national cultivar registration scheme."

Bt Cotton Diffusion and Variety Market Development

In China, numerous varieties have been offered to cotton growers over the years bred mostly for their improved adaptation to the local physical and climatic conditions of the production region. The cotton breeding capacity in China, as measured by number of varieties offered and the organizations involved, has nevertheless been further enhanced since 2000 spurred by the new related institutional framework.

Clearly, the rate of new variety offering was greater after 2000 than before, as indicated in Column A of Table 2, corresponding to the total number of recorded varieties which had surpassed the area thresholds (ranging from 667 to 6,667 ha, respectively, depending on the year). According to the NATESC cultivar area data, a total of 571 varieties were cropped throughout the 1990-2006 period, but in the shorter 2000-2007 period, the total number of varieties recorded was far higher than before 2000 (372 vs. 199). There were actually 73 varieties recorded in the two periods, which means that almost 300 new varieties have been released and used since 2000.

The variety-market development is also illustrated by the number and diversity of breeding organizations involved. Cotton breeding used to be implemented by educational organizations (colleges and universities), research institutes and local agricultural departments. According to data of the national cultivar registration scheme, private firms have been active since 2000 (Table 3). All of the identified 156 organizations were

Table 3. Distribution of the breeding units having submitted varieties for national registration.

Administrative level of breeding organisations' headquarters	Firms	Colleges/ universities	Research institutes	Agri departments	Total
County	9	1	11	1	**22**
District	35	1	31	1	**68**
Province	17	11	26	3	**57**
Central	2	1	6		**9**
Total	**63**	**14**	**74**	**5**	**156**

Note: from "National cultivar registration scheme"

Table 4. Evolution of the numbers of varieties submitted for national registration.

	No. varieties submitted	Share of no. varieties submitted in total (%)		No. varieties by private companies	Share of no. varieties submitted by private companies (%)	
		Hybrid cultivars	Bt cultivars		Hybrid cultivars	Bt cultivars
1999	9	33.3	0.0			
2000	27	44.4	44.4	1	0.0	100.0
2001	55	29.1	27.3	3	0.0	0.0
2002	72	27.8	48.6	5	0.0	20.0
2003	76	32.9	71.1	10	10.0	30.0
2004	73	32.9	71.2	20	40.0	65.0
2005	94	55.3	75.5	27	63.0	74.1
2006	115	62.6	87.0	31	61.3	80.6
2007	113	58.4	85.8	37	62.2	89.2
Total	**634**	**45.7**	**68.8**	**134**	**50.7**	**71.6**

Note: from NPVPO data

mainly located at decentralized administrative levels (province, district, or county). Research institutes remained the top group of breeding organizations, but private firms were catching up. This trend clearly shows that China has succeeded in its policy of promoting variety and seed market development. The market remains quite competitive, and issues of industry concentration or potential presence of market power that have surfaced in the US (e.g., Kalaitzandonakes, Magnier, & Miller, 2010) are not present in China.

It is worth mentioning the quality boost that was achieved along with the variety market development, notably through the modernization of the cotton-seed market from the release of Bt-cotton seeds (Fok & Xu, 2007). Marketed seeds were all delinted. Packaging was tailored to producers' needs (cotton could be grown on one mu, i.e., one-fifteenth of a hectare), which was far more attractive and high seed germination rates were guaranteed. All of the many new advertisements promoting new varieties stressed these aspects. When fake seeds appeared in the market, Monsanto set up hotlines to enable purchasers to check the authenticity of the seeds they bought through verification of the package codes. This has been a positive side effect from the marketing of US Bt-cotton varieties that also illustrates the causal relationship between Bt-cotton marketing and seed market development. This link was most evident in provinces where hybrid cultivars were almost exclusively used (see Table 6).

Bt-cotton diffusion has contributed to the development of the variety market, and in return, this development has favored the use of varieties that combine the Bt feature with the hybrid feature in provinces where transplanting was practiced. The relationship between the variety-market dynamics and biotechnology innovation is consistent with the pattern noted in the United States with respect to corn and soybean varietal development (Magnier, Kalaitzandonakes, & Miller, 2010), but the orientation toward hybrid varieties, at least in provinces where their agronomic advantages were well acknowledged by farmers, is specific to China. Over the 1999-2007 period, 634 varieties were submitted for national registration. For all types of breeding service, including private companies, there was a clear trend in favor of breeding Bt-cotton varieties or hybrid varieties (Table 4). In 2007, new Bt-cotton varieties accounted for more than 85% of the total (up to 90% when only private breeding companies were considered). The pro-

Table 5. Evolution of variety numbers according to variety types and the location headquarters of the breeding organizations (with reference to YaRV).

		1999	2000	2004	2007
Breeding organizations out of YaRV	**No. varieties**	5	17	57	79
	NH-NBt, %	80	41	32	19
	NH-Bt, %	0	29	42	37
	H-NBt, %	20	6	0	0
	H-Bt, %	0	24	26	44
Breeding organizations in YaRV	**No. varieties**	4	10	16	34
	NH-NBt, %	50	30	6	0
	NH-Bt, %	0	0	38	9
	H-NBt, %	50	40	12	3
	H-Bt, %	0	30	44	88

Note: H = hybrid; NH = non-hybrid; NBt = non-Bt; from NPVPO data

Table 6. Hybrid and Bt shares of cotton areas in three zones (% of totals in each zone).

	All China				Jiangsu Province				Hebei Province			
	NH-NBt	NH-Bt	H-NBt	H-Bt	NH-NBt	NH-Bt	H-NBt	H-Bt	NH-NBt	NH-Bt	H-NBt	H-Bt
1996	96	0	4	0	100	0	0	0	96	0	4	0
1997	91	3	6	0	100	0	0	0	77	23	0	0
1998	84	7	9	0	97	0	3	0	29	71	0	0
1999	73	19	6	1	94	0	3	3	10	90	0	0
2000	48	37	12	2	93	0	0	7	0	95	0	5
2001	45	40	9	5	90	0	0	10	5	84	0	11
2002	41	39	9	11	65	12	0	23	5	87	0	9
2003	29	51	7	13	40	22	0	38	2	97	0	1
2004	26	53	5	17	12	29	8	51	0	100	0	0
2005	23	52	6	19	18	19	4	60	0	100	0	0
2006	24	46	6	23	13	9	6	71	3	92	0	5

Note: H= hybrid; NH = Non-hybrid; NBt = non-Bt from NATESC cultivar area data

portion of hybrid varieties bred exceeded 60% (in the case of private breeding companies).

A more in-depth analysis of the national cultivar registration scheme data clearly highlighted the trend to combine Bt and hybrid features. We assumed that breeding organizations had to offer varieties adapted to the areas in which their headquarters were located. We focused especially on YaRV where cotton transplanting was widespread and where hybrid varieties might be favored. Table 5 clearly shows that hybrid varieties accounted for close to 90% of all varieties for breeding organizations originating from YaRV, which was far higher than for organizations headquartered in different regions.

The variety market development trend in favor of Bt or hybrid features was consistent with farmers' adoption of varieties, as observed in two representative provinces, Jiangsu for YaRV and Hebei for YeRV, which diverged notably with respect to the cotton transplanting practice (Table 6). In areas where pest resistance to insecticides had seriously hampered cotton production, as in Hebei Province, Bt-cotton adoption was almost complete, but hybrid varieties were seldom used there and transplanting was not extensively practiced. In regions where that technique was widely practiced, as in Jiangsu Province, hybrid varieties accounted for about 80% of the total cotton area, with almost all varieties also combining the Bt trait. At a national level there is still more than 20% of the cotton hectares that do not use Bt varieties. This lack of use is a point that deserves more in-depth analysis and might be related to lower pressure by target pests of Bt-cotton.

While most previous studies have only provided information at the national level, we have provided here information on Bt-cotton adoption at production valley or province levels and our national data are consistent with former findings. Bt-cotton accounts for about 70% of the total cotton area in China, as previously mentioned. This figure is also consistent with the share of Bt varieties among the new varieties involved in the national registration process. Hybrid cultivars account for slightly less than 30%, most combining the Bt trait at the same time.

Variety Market Structure and Implications

Data Used

We further exploit the NATESC cultivar area data here through multiyear analysis to determine the market lifespan of the recorded cultivars as an indicator of the variety market competition. This lifespan was calculated by the number of years a given cultivar had been recorded on areas above the 6,667 ha threshold.

Historically, it has been difficult to construct complete data series of cotton seed prices and to analyze the relationship between market competition and seed prices. Recently, NATESC started compiling seed price data in various cotton producing provinces. The prices were given by variety for which their nature (hybrid and Bt nature) could be identified and verified. After verification, a total of 171 data records relating to 94 varieties, called the "NATESC seed price records," were processed to assess current seed price levels and price gaps according to variety nature and provinces used.

The above mentioned price series were too recent to be able to assess patterns of price movements over time. For this reason, we tried to complement the NATESC seed price records by reviewing many published papers in Chinese and other languages. Through such a procedure, we collected data on 36 seed price series, 18 of which pertain to Bt and hybrid seeds, for the 2001-2007 period.

Finally, in order to determine how Chinese professionals in the cotton sector perceived the development and competition in the variety market, we analyzed scientific papers published in Chinese, hence relatively inaccessible to the international community. Papers that questioned the profitability and sustainability of Bt-cotton in China began appearing in 2003, before the international community became aware of this controversy (Wang et al., 2006). Most of these papers were extracted from the proceedings of annual cotton research conferences in China, which gave updated information on the technical issues and contemplated or tested solutions.

Strong Competition and Implications on Seed Quality and Prices

Dynamism in breeding and the development of new varieties appears closely related to strong competition in the market. Column B in Table 2 corresponds to the number of varieties cropped on an area above the 6,667 ha threshold for at least 1 year during each of the two periods considered (1990-1999 and 2000-2006). In the second period, the number of new varieties developed increased while the average hectareage of use per variety declined relative to the first period. Indeed, a third of the commercially released varieties did not achieve even minimal market success (i.e., cultivated on more than 6,667 ha for at least 1 year). This is consistent with the trend of shorter product cycles noted for corn hybrids in the United States where a substantial share of varieties had been removed from the market after a year (Magnier et al., 2010).

The intensity of market competition was also illustrated by the reduction in the potential market share of each variety. Given the total area recorded for all varieties (Column C in Table 2) and assuming that the market was equally distributed between varieties, the total area per variety can be deduced for each period (Column D in Table 2) as an indication of the potential market share, or the mean area per year (Column E in Table 2). Apart from Hebei province (where Monsanto varieties dominated among a small number of new varieties), the average annual area per variety significantly decreased over time.

The market would not generally be expected to be equally distributed among varieties, however. Market concentration had historically been high but has declined somewhat in recent years. This concentration could be estimated on the basis of "area shares" of varieties, although the estimation is more precise when only hybrid varieties are considered (for non-hybrid varieties, the real market shares are lower since farmers do not necessarily buy seeds every year). According to the NATESC area data, and when considering the eight cotton provinces, the area shares of the Top 1, Top 3, and Top 5 varieties were, on average, respectively 37%, 71%, and 82% in 1990. These shares steadily declined to 16%, 32%, and 42% in 2006, but given the great number of commercially released varieties, the market concentration still remains high.

The increase in the intensity of market competition is clearly illustrated by the shortening of the commercial life of cotton varieties. Based on NATESC area data, the market lifespan was calculated for all 571 varieties grown during the 1990-2006 period. Overall, about a third of all marketed varieties had a market lifespan of 1 year in all provinces. More than 60% of the varieties had a lifespan of 3 years at most. For more than 80% of the varieties, their lifespan was at most 5 years. In the United States, Magnier et al. (2010) also noted that the average lifespan of varieties declined over time and, on average, was less than 5 years.

The high variety turnover seems to be sustained by the farmers' responsiveness to the supply of novelties, as noted in places where hybrids or non-hybrids prevailed. In a survey of 176 farmers in Jiangsu province, it was noted that they showed high versatility in the varieties they used during the 2004 and 2005 crop seasons: 14 were maintained from 2004 to 2005, whereas seven were abandoned after 2004 and 12 new ones were used for the first time in 2005 (Fok & Xu, 2007). The farmers' preferences were concentrated on a small number of varieties, all hybrids. The most preferred variety was adopted by 25% to 37% of all farmers. About 75% of the farmers were using one or more of the top five varieties, which is consistent with our results from the NATESC area data and reported above. In Hebei province where hybrid cultivars were seldom used, 217 farmers studied frequently grew two to three varieties on a total area of one-third of a hectare, thus also demonstrating the common tendency to test new varieties (Fok et al., 2005).

Not only was competition among varieties intense, it was also unfair because of the uncertain and fake nature of a substantial share of varieties. Cheating on the nature of the varieties or on the quality of the seeds was reported soon after the commercial release of Bt-cotton (Pray et al., 2001). This phenomenon has been exacerbated according to the Chinese publications we analyzed (Lu, Tian, & Zhang, 2006). More specifically, in Hebei province, it was found that over the 2006-2009 period, 42.6% of the names of varieties declared by farmers did not match the list of officially registered varieties (Wang & Fok, forthcoming).

The inherent uncertainty in the market is illustrated by the unclear Bt nature of some varieties, even after several years of SL application. False declarations about the nature of marketed varieties were discovered through analysis of the NATESC seed price records. In 2007, price information was collected on 79 varieties, including 37 that were officially non-Bt cotton varieties. Interactions with the network of cotton breeders helped us discover that 21 of these 37 varieties were indeed Bt varieties and probably marketed as such. In 2008, records were available for a total of 45 varieties, six of which were officially non-Bt, but in reality all contained Bt genes. The NATESC seed price records were nevertheless not exhaustive and the phenomenon of false declarations on the non-Bt-cotton nature might not be representative.

Table 7. Average seed price according to variety types and provinces (standard deviation within brackets), RMB/kg.

		Non-hybrid		Hybrid
Province		**Non-Bt**	**Bt**	**Bt**
Hebei	**2007**		27 (10)	95 (13)
	2008		44 (20)	110 (14)
Hubei	**2007**			105 (55)
	2008			162 (13)
Hunan	**2007**			162 (12)
Jiangsu	**2007**			118 (30)
	2008			120 (32)
Shandong	**2007**		26 (15)	72 (11)
	2008		29 (15)	82 (8)
Xinjiang	**2007**	4 (2)		
Zhejiang	**2008**			165 (33)

Note: from "NATESC seed price records"

The extent to which intense and unfair competition is related to high seed prices is unclear. As noted above, former studies highlighted the fact that farmers complained about the high Bt-cotton seed prices. Our data supported the increasing seed price trend, but they were not sufficient to clearly confirm a link to the intensity and nature of market competition.

There were marked seed price differences between the different variety types. When the demand of individual varieties began to increase after their initial introduction, their prices rose. According to the NATESC seed price records, non-Bt and non-hybrid varieties were only used in Xinjiang province (Table 7), with an average seed cost of 4 renminbi (RMB) per kilogram (for the period considered, the RMB to euro exchange rate was 10 to 1 on average). Seeds of non-hybrid Bt-cotton varieties fluctuated from 26 to 44 RMB/kg between provinces, with rather high standard deviations. The addition of the Bt feature to non-hybrid varieties generally boosted the price by six- to eleven-fold. The prices recorded for hybrids all pertained to Bt-cotton. They ranged from 72 to 165 RMB/kg between provinces, with relatively low standard deviations. With price records only available for 2 years, no general trends could be detected. It is worth noting that the price mark-ups due to biotechnology in China were much higher than observed in the United States (Kalaitzandonakes et al., 2010).

A rapid increase in seed prices could be observed after 2000 when the role of private firms began increasing. With regard to the price data we collected through analyzing papers published in China, we observed that the price levels were comparable to those NATESC recorded for the last crop seasons, at 100 to 120 RMB/kg, but they were 30 to 45 RMB/kg until 2003 before the dramatic increase. The price increase typically occurred 3 years after the market introduction and continued through the market development period of varieties. Several other factors could underlie the high seed price phenomenon, especially when considering hybrid seeds obtained through manual fertilization. Labor costs in rural areas have increased substantially. According to the breeders we interviewed, the daily labor cost for manual fertilization remained steady at 10 RMB from 1995 to 2002, and then rose to 18 and 25 RMB in 2004 and 2007, respectively. This labor-cost increase could be related to the general increase resulting from the global economic development in China, but more directly to the shortage of labor in rural areas as a consequence of rural outmigration to cities where salaries are higher.

Although it may be counter to standard economic theory, it is possible to hypothesize a direct relationship between intense competition and high pricing. Owing to the short market lifespan of cotton varieties, variety development and distribution costs must be recovered within short periods, which could be an economic rationale for increasing seed prices (Magnier et al., 2010). While we cannot directly test such a hypothesis with our data, it is worth consideration and requires further study.

Irrespective of the possible relationship between market competition and seed pricing, the observed high pricing could prompt some stakeholders to market fake products, hence making competition even more intense and unfair. Under such circumstances, farmers would suffer from high seed prices that would not necessarily be a guarantee of high seed quality and performance. Indeed, farmers have frequently complained about paying high prices for poor quality seed. Such complaints have been confirmed by parallel concerns expressed by breeders and seed distributors with respect to the viability of their businesses, who denounced the “seed market disorder” (Lu et al., 2006; Zhang, Guo, Chen, & Zhou, 2006) and requested regulation.

Market Regulation through Debatable Modalities

The Chinese government eventually responded to the request for regulation because the uncertainty on the variety nature and seed quality had negative implications for farmers, the cotton sector, and the future of biotechnology in agriculture. Pemsl, Waibel, and Gutierrez (2005) pointed out that the uncertainty on varieties and seeds prompted farmers to spray more chemicals than required, thereby reducing the profitability and increasing the toxic effects on biotic systems. Because high seed prices were not necessarily a reliable indication of variety and seed quality, it was noted that farmers tended to buy cheaper seeds and tried to compensate for this by implementing precautious chemical control (Pemsl & Waibel, 2007). This farmers’ adaptation actually could nullify the advantage Bt-cotton as farmers could lose confidence in their ability to assess the true quality of transgenic varieties.

The quality seed subsidy policy (QSSP) was adopted in early 2007 (“Farmers to receive,” 2007; International Cotton Advisory Committee, 2010) before the cotton cropping season to regulate this situation. This policy was planned to last four years. In 2007, the subsidy fund was set at 500 million RMB (or about €50 million) for an estimated cotton area of 2.7 million ha. The subsidy allocation was differentiated, i.e., 150 RMB/ha in the western region of Xinjiang and 225 RMB/ha in the other provinces. The objective was to generally cover 50% of cotton growers’ seed cost.

The objectives of the subsidy policy were twofold. The subsidy was designed to directly decrease growers’ production cost so as to boost their income. Applied only to a short list of varieties, the subsidy was aimed at influencing the orientation of the seed market structure in order to eliminate seed companies unable to provide quality seeds to farmers.

Debatable Regulation Spirit

The QSSP was the first measure to support cotton production after China joined the World Trade Organization. In practice subsidies were managed through a decentralized process and in compliance with the SL. Subsidies were allocated to farmers who bought seeds of varieties on an eligible list drawn up by each province and district. In practice, when farmers purchased seeds, they only paid the price differential between the total price and the subsidy. It was up to the seed distributor to get the subsidy from the local administration in charge of the subsidy program.

The modality of restricting the subsidy program to a pre-determined list of varieties kind of dictated the varieties farmers should use and violated Article 39 of the SL. Besides, as the subsidy was associated with the purchase of seeds, the QSSP promoted a bias that discriminated against farmers who did not buy seeds, while Article 27 of the SL permits farmers to use seeds of their own and to trade or sell them to other farmers.

Clearly, the new subsidy policy gave back influence to local authorities in an economic sector that had become autonomous following application of the PVPA and SL, hence providing opportunities for a few stakeholders to wield their administrative power. Even if the listing process were objectively implemented, it is unlikely that an administration could know what varieties and seeds would be best tailored to farmers' requirements and expectations.

Debatable Regulation Outcomes

After a year of implementation, it was already noted that the new policy would likely not achieve the expected target (Wang & Lou, 2007; Yang, 2007), mainly because of its modalities of implementation, in terms of lack of transparency and coordination. In the short run, the impact of the QSSP to improve seed quality was mitigated because of the poor quality of seeds of a few varieties that had been declared eligible for subsidy (Yang, 2007). It was also noted that the amounts of seeds available for several varieties were limited and hence insufficient given the farmers' demand. These observations raised questions about the process of selecting the list of eligible varieties. No one we interviewed could provide information on the selection rules, and there was no trace of written rules in any cotton-producing provinces. In practice they varied between provinces.

The impact of the QSSP with respect to rectifying the seed market was also questionable. Amazing results were nevertheless observed. A small company with a marginal market share could suddenly see its development promoted if it had varieties being listed (Wang & Lou, 2007). How such a small company could be selected raises questions. Conversely, a well-established company with appreciated seeds and services that enjoyed a substantial market share might see its development suddenly stalled because a limited number of its varieties were listed or eligible only to a limited number of districts.

The potential impact of the QSSP might contrast with the objective of cleaning up the market. Since the economic fate of a seed company depended on whether its varieties were listed, it might have been more effective to focus on influencing variety listing decisions, therefore upsetting the nature of market competition, which could become less fair between varieties. Consequently, relevant market stakeholders could be eliminated in favor of seed companies lacking sense of fairness in doing business.

The QSSP could also hamper innovation because farmers were price sensitive and this behavior could lead them to turn their back on innovative new varieties. In 2007, the subsidy amount was set regardless of the type of seeds farmers used or bought, it was designed to halve the seed cost farmers had to pay when they bought good-quality hybrid seeds. This meant that farmers had to pay proportionally more when they purchased high price seeds. In trying to reduce production costs, farmers could favor cheaper seeds, hence turning their back to more innovative varieties of which development could warrant higher seed prices. Prolonged, this bias could halt the variety-breeding innovation process.

Control of Seed Production is Overlooked

To several observers of variety and seed markets in China, the critical issue is the lack of control and certification of seeds at the local level after the institutional shift to promote variety and seed markets (Liu, 2006; Lu et al., 2006). Although rules were set through the SL to charge the local administrations of the control and certification, the related services have remained insufficiently staffed and underfunded to properly implement seed control and certification.

The uncertainty about the nature of varieties and the seed quality (Wang & Fok, Forthcoming) has resulted from a lack of real control at the seed production stage. Informally, it has been reported that in the same village, several varieties or types of varieties (Bt, hybrid or not) could be multiplied simultaneously for seed production, when a single farmer was not contracting for the multiplication of several varieties (Liu, 2006). It is therefore clear that it would be hard to preserve seed purity under such production circumstances given the tiny size of villages and farm holdings in China. Even the most basic seed-quality criterion, i.e., germination rate, has not always been paid close attention to. Germination rates have often been reported at levels below 60%, far below the generally accepted threshold of 98% (Lu et al., 2006). Under such circumstances, the frequent complaints about insufficient seed quality appear to be well founded. Amazingly, the launched seed quality policy does not at all address seed control schemes (Yang, 2007). It would be reasonable to determine the seriousness and reliability of individual seed companies by assessing the way seed production supervision has been implemented. Unfortunately, this has not yet been considered.

Conclusion

The advent of Bt cotton has led to a real rebirth in cotton production in areas hit by serious pesticide resistance in bollworms like *Helicoverpa armigera*. The already observed regression in profitability (Wang et al., 2008), however, questions the sustainability of the broad Bt-cotton diffusion and calls upon a more comprehensive understanding of the underlying diffusion factors. This article is a contribution to this debate as it focuses on the variety market development process.

In China, Bt-cotton diffusion has coincided with a dramatic institutional change in cotton variety development and seed markets. This change certainly encouraged Monsanto, and its seed ally the Delta & Pineland Company, to enter the Chinese market in order to release their varieties and to contribute to the modernization of the seed sector. We found that, at the same time, the development of cotton variety and seed markets has benefited Bt-cotton diffusion. This was particularly clear in provinces where hybrid cultivars were grown because of their compatibility with the transplanting technique and where almost all hybrid varieties integrated the Bt trait.

The development of the variety market has nevertheless led to intense competition. The number of marketed varieties has been on the increase, a phenomenon that has also been fostered by farmers' responsiveness to novelties. Consequently, the market lifespan of varieties was found to be shrinking, implying that the cost of developing and disseminating new varieties had to be recovered in a shorter period. This might be one factor that has contributed to the price increases observed in cotton seeds. If so, this would be an impact counter to standard economic theory in the sense that stronger competition might have led to price increases. The data we tapped did not enable us to fully confirm this point, and further studies are needed to explore other factors potentially responsible for high seed prices.

Competition was also unfair because of presence of fake varieties and seeds. High seed prices encouraged unscrupulous initiatives to supply counterfeit seeds. Farmers have been paying high seed price to obtain poor quality seeds, thus confirming the so-called seed market disorder that has prevailed in China since 2005.

The international debate about the release of GM varieties is still greatly overshadowed by the fear of monopolistic power or lack of competition. The case of China shows that competition alone would not be sufficient to ensure sustainable and fair outcomes. Competition still requires regulation. The Chinese government responded in 2007 by implementing the QSSP, the spirit and outcomes of which were still quite debatable. Real control of seed production is now crucial.

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