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Reforming intellectual property rights and the Bt cotton seed industry in China: Who benefits from policy reform?☆

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ABSTRACT

China has been one of the leaders in agricultural biotechnology research and the adoption of transgenic plants. Despite this, critics argue that China's biotechnology policies could be improved to provide more benefits to farmers. The objective of the paper is to examine if policy changes could improve the welfare of farmers in the cotton industry. The paper first reviews recent changes in laws and policies that affect China's plant biotechnology sector—with a focus on IPR legislation and seed industry reform. Next, using a primary data set collected from 1661 plots from a sample of farmers in northern China in 1999, 2000 and 2001, we econometrically estimate the effect of changes to intellectual property rights (IPR) and seed industry reform on farmer pesticide use and yields. Our results are consistent with a conclusion that improvements to the IPR environment and greater commercialization of the seed industry can increase the benefits that farmers derive from new cotton technology.

1. Introduction

Until recently, China's government successfully raised the productivity of the agricultural sector with new plant varieties and other modern inputs (Zhang and Fan, 1999; Fan, 1999). Because of a number of perceived problems with the public-sector dominated system, since the mid-1990s reformers have tried to encourage new institutional approaches to develop and disseminate new varieties. Leaders have passed a number of new laws governing intellectual property rights (IPRs). Officials are experimenting with new biosafety management approaches. There are new initiatives pushing for the commercialization of the crop breeding system and seed industry (Louwaavs et al., 2005). In many of the efforts the private sector is being encouraged to play a larger role. In the case of the cotton industry the government has allowed joint ventures between international companies and domestic seed firms to commercialize genetically modified (GM) cotton. While it is clear that there are still weaknesses with China's IPR environment and seed industry reforms, a number of studies have documented the success of China's GM cotton technology in increasing the productivity of farmers (Pray et al., 2001, 2002; Huang et al., 2002a,b; Jia, 2004; Wu and Guo, 2005; Yang et al., 2005a,b).

Despite past successes, a number of questions remain about the sustainability of the way China is developing and extending agricultural technology. Will weaknesses in the IPR environment in China hurt the effectiveness of the technology that is in the field? Are the seed reforms working? Are new seed firms providing farmers with high quality seeds? Do seeds that come from foreign, joint venture firms (using foreign-produced genetic material) outperform those of domestic firms?

The overall goal of this paper is to help answer these questions. We seek to do so by quantifying some of the benefits of reforming China's IPRs and seed industry policies. We explore the benefits of two sets of policy reforms: (a) increasing the scope and improving the enforcement of IPRs; and (b) reforming the policies that govern the seed industry.

The main contribution of our paper is that it analyzes the effect of these policies using microeconomic models of household and firm behavior in China. Although the literature contains much discussion on the emergence of IPR and seed reforms, there are few studies that *empirically* link the policies with the production behavior of farmers.

Because the scope of our work is so broad, however, we necessarily must limit its scope. For example, the paper examines empirically the impact of biotechnology management policies on

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the production of farmers (use of pesticides and yields). Unfortunately, while it is important to consider enforcement costs, we have little information on such costs. Likewise, although we analyze which types of seed allow farmers to use less pesticides and have higher yields, our data do not allow us to identify the precise reason (e.g., agronomic or pathology) why pesticide use is higher and yields are lower.

2. Reforms in China: IPR and the seed industry

2.1. Intellectual property rights (IPR)

Prior to the late 1990s it was legal for a seed company to reproduce a variety of another company for the purpose of marketing the new variety. There also were no restrictions on the use of another breeder's variety as a parent in the development of another variety. The new variety could be sold and marketed legally without paying any licensing fees or royalties to the original creators of the parent varieties. The use of varieties of other breeders as parents was a common practice in the 1980s and early 1990s for all crops (The State Council, 1997).

Despite the availability of Plant Varietal Protection (PVP) for most of China's crops since 1997, protection is still not very strong and the crop which is considered in this study, cotton, was excluded from protection until 2005. China's laws also do not restrict the use of protected varieties as parents in the production of other varieties. China's PVP legislation has a research exemption that explicitly allows research institutes and seed companies to use PVP varieties as parents to develop new varieties. PVP does not give proprietary protection to genes but new genes can be covered by patents in China.

In response to these loopholes in the PVP laws and their enforcement, research institutes and seed companies have taken actions to prevent their proprietary varieties and novel genes from being used by other scientists without permission or at least begin to receive royalties. Above all, the seed industry is beginning to use the patent system. For example, Dr. Guo Sandui of the Chinese Academy of Agricultural Sciences (CAAS) received a patent on the Bt gene that he developed. This gene (henceforth, the *CAAS gene*) is being used in all of the China-produced varieties that are being sold by a CAAS (fully domestic) joint venture enterprise (henceforth, Biocentury—Fang et al., 2001). Monsanto also has patents on several genes that are important in the production of transgenic plant varieties, although it did not patent its initial Cry1Ac Bt gene in China (henceforth, the *Monsanto gene*). Monsanto genes are legitimately found in the seeds sold by two joint venture seed enterprises set up originally by two foreign-owned life science firms, Monsanto and Delta and Pine Land (DP). In the past decade these foreign-owned firms partnered with two different provincial seed companies (Jidai in Hebei and Andai in Anhui—henceforth, both JVs are called *Jidai* for convenience). The CAAS and Monsanto Bt genes are inserted into plants to make them resistant to certain classes of insects. In particular, the patents cover processes that create transgenic cotton varieties.

Research institutes and seed firms also can try to use trademarks – another form of IPR – to protect their technology (Louwaavs et al., 2005). Biocentury has trademark protection on its name and on the names of some components of their technology (Fang et al., 2001). Jidai uses Monsanto's Bollgard trademark on its Bt cotton varieties to try to prevent other firms from using the name on their varieties.

While some seed companies in the cotton industry have taken steps to protect their seed varieties, their actions do not appear to have helped keep other companies from appropriating their technology. Interviews with CAAS, Biocentury, Monsanto and Jidai managers and research administrators reveal that few people believe that the current system of IPRs – and the way that the regulations are being enforced – provide effective protection for the plant technologies that are patented, have plant variety certificates or have trademarks. Cotton seed firms have had little success in keeping other firms from copying their genetic technologies or trademarks. Seed companies in the Bt cotton seed market still regularly reproduce, backcross and market the varieties developed by both Biocentury and Jidai.

2.2. Reforms to the seed industry

In recent years changes also have been occurring in the seed industry. As late as the mid-1990s local and regional state-owned enterprise (SOE) seed monopolies dominated China's seed industry (Qian, 1999; Keeley, 2003; Li and Yan, 2005; Huang et al., 1999). In total, 2700 SOEs operated in their local counties, prefectures and provinces. In many counties only the local SOE was allowed to sell seeds of the major crops. Regulations banned the participation of non-SOE seed firms in the production, distribution and sale of hybrid maize and rice. In the typical case the county-based SOEs sold their seed through township agricultural extension agents (which in the rest of the paper we will call a traditional, non-commercial seed sales channel). Indeed, during the 1990s agricultural extension agents earned a large share of their income from selling agricultural inputs, including seed. In addition, seed also flowed to farmers through other traditional, non-commercial channels, such as the cotton office (originally – through the late 1990s – the cotton office was the state-designated cotton monopoly procurement agency; it was turned into a cotton technology extension and cotton policy administrative agency after 1998) and seed production bases (which are villages or groups of villages that have contracts with the former SOEs for the reproduction of their seed).

The evolution of the seed industry continued after the late 1990s. In 2000 the government passed a new seed law that for the first time legally defined a role for the private sector. All firms – private, quasi-commercialized SOEs and traditional SOEs – were allowed to apply for permits to sell seed in any jurisdiction. Measures also were put into place that allowed firms to have their seeds certified at the provincial level which would entitle them to sell seed in any county in the province. By late 2001 nine companies had permits to sell seed anywhere in the country. For the first time it became feasible for national companies to establish their own distribution and retail networks. At the other end of the spectrum hundreds of small seed companies opened up to supply local needs.

Since the mid 1990s the laws and policies that govern the seed industry have changed in such a way that a commercial and competitive seed industry has begun to evolve (Keeley, 2003; Li and Yan, 2005). Among other parts of the legislation, the law makes it clear that any entrepreneur that has access to the required minimum amount capital and facilities can sell seed. Private companies are allowed to sell seed (including any variety of GM or non-GM cotton) that was bred by public breeding institutes. With the passage of this legislation, the legal protection of the monopoly positions of county, prefectural and provincial seed companies was formally removed.

As the reforms began to be implemented, commercial seed distribution channels for seeds opened along side the networks through which agricultural extension agents (and personnel in cotton offices and seed production bases) had traditionally sold seed to farmers. New sources of investment in the industry have emerged. For example, domestic entrepreneurs invested in private seed firms. Some of the traditional SOEs have transformed themselves into commercial firms. Although they are still few in number and are required to sell through a joint venture with a Chinese firm, foreign firms have begun to invest in China's seed industry.

In the cotton seed industry – especially in the part of the industry that is involved in the creation and marketing of GM cotton – the government's recent policy efforts appear to have been effective in encouraging the development of a commercial seed industry. Specifically, there have been three fundamental shifts in the structure of the cotton seed industry: the appearance of large commercial seed companies that operate at the regional or national level; the rise of private foreign firms (although they still play a somewhat limited role); and the emergence of small, private cotton seed firms. Despite these shifts, field visits make it clear that the traditional seed producers (the local SOE seed enterprises) and their distribution channels (agricultural extension system, cotton offices and seed production bases) are still active.

3. Defining and identifying seed types and hypotheses

To analyze the effect of IPR improvements and seed industry reforms, we developed the following four step research design. The first step defined the different categories of distinct seed types. The second step created a set of survey questions that allowed us to collect information from farmers about their use of the different types of seeds. The third step examined descriptively what our data set says about the use by farmers of the different seed types in our sample area. The fourth and final step developed the hypotheses to be tested in the rest of the paper.

3.1. Defining seed types

In this paper we specify three criteria that define a seed type. The first criterion is the source of the seed. In our categorization, there are three main channels through which farmers can access the Bt cotton seed that they use. They can purchase seed from a commercial seller. These seed types are called *commercial seed* or *seed from commercial sources*. Farmers also can purchase seed from agents that we say are part of the traditional or non-commercial seed sector. These seed types are called *non-commercial* seed. Farmers also save their own seed. The seed that is saved is called *saved* seed.

The second criterion refers to whether or not the seed is produced by a *foreign* (Jidai) seed company using genetic material that was developed by a foreign (Monsanto) research firm; or a *domestic* seed company (Biocentury) using genetic material that was developed by a domestic research institute (CAAS). While there potentially are other varieties that are produced by domestic (foreign) companies using domestic (foreign) genetic material, in the rest of the paper, foreign seeds are called Jidai/Monsanto and domestic seed are called Biocentury/CAAS.

The final characteristic/trait relates to the new IPR regulations which have allowed seed firms to (a) patent the processes by which the genetic material in their varieties has been produced; and (b) brand their names with a trademark. If seed is produced and distributed by the company that has the patent for the processes that created its genetic material and if it holds the trademark over the official name of the variety under which it is being sold, the seed is *legitimate*. If it is sold by a company that does not hold the patent or the trademark, the seed is *illegitimate*.

3.2. Enumerating seed types

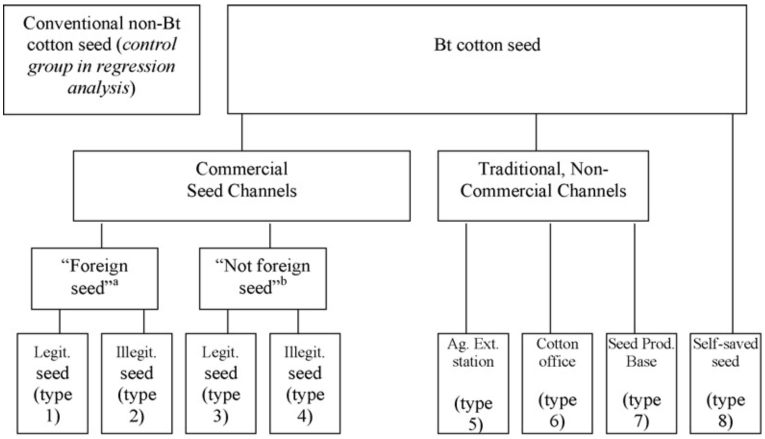
During our surveys, enumerators were able to identify the different types of seeds that farmers used by asking them a series of questions that were designed to distinguish one type from another which could then be traced back to IPR and seed reform policies. The most straightforward characteristic to identify was the source of the seed—commercial or non-commercial. All farmers know who their local agricultural extension agents are. All farmers also know what the cotton office is. They also know where the local seed production bases are located. We asked the farmer if they purchased their seed from agricultural extension agent, cotton office or seed production base. If the answer was yes, the seed was non-commercial seed. If the seed was purchased from any other source, it was commercial seed. If the seed was not purchased but was from the farmer's own stocks, it was self-saved.

Although it was more difficult to identify the other two characteristics—if seeds were foreign/domestic or legitimate/illegitimate, we believe we were able to do so for the case of commercial seed. When a farmer purchased seed from a commercial source and we asked for the variety name, the country of origin of the seed and its price. In nearly all cases the farmers had no difficulty in telling us this information. In particular, farmers were almost always certain that a seed was foreign or not foreign. Since their introduction in 1997, farmers were always interested if the variety was foreign or not. As such this is a topic of discussion during almost all sales transactions. The question is frequently phrased as: "is this seed 33b?" (which is the common name for the seed with the Monsanto genetic material sold by Jidai). The other trademarks of Jidai and Biocentury also are well known. As a consequence, we were able to use this information, to identify if commercial seed was foreign or domestic with a fairly high degree of confidence.

Determining if commercial seed was legitimate or not was more difficult. The same farmers that knew if a variety was foreign or domestic often were not sure whether the seed company from which they bought their seed was actually selling legitimate seed or not (that is if they were actually produced and distributed by either Jidai or Biocentury or their authorized partners and/or dealers). Therefore, we have had to rely on certain assumptions in assigning legitimacy to the Jidai or Biocentury seed types. Specifically, from our field work during the time that we collected our data we discovered that the legitimacy of seed could be largely determined by looking at the price that farmers paid for their seed and whether or not the seed was delinted and/or treated. Legitimate Jidai and Biocentury seed was always delinted and treated; legitimate seed also was nearly always sold for a fixed price, about 45 yuan/kg (although in some cases there was a slight discount). As a consequence, when farmers reported that they bought seed for less than 30 yuan/kg, even when they called the seed 33B, we assume that they were buying illegitimate, foreign seed. Likewise, if the farmers said that his domestic seed (*guonei pingzhong*) was treated, delinted and priced at 40 yuan/kg, we assume that farmers were buying legitimate, domestic seed.

Unfortunately, we are only able to identify the two distinct characteristics of seed – foreign/domestic; legitimate/illegitimate – *for seed that was purchased by farmers from commercial sources*. In the late 1990s and early 2000s seed from non-commercial sources often did not have trademarks and were sometimes sold by bulk or distributed in plain bags. Because of this, farmers in some villages found it difficult to identify the exact origin of their seed from non-commercial sources. Therefore, it was impossible in some cases for enumerators to know whether the seed that farmers purchased from non-commercial channel (or seed that was saved) was foreign or domestic. In addition, because the pricing of legitimate and illegitimate non-commercial seed was less clear than the case of commercial seed, it also was more difficult to know if non-commercial seed was legitimate or non-legitimate.

Fig. 1 summarizes the criteria by which different seed types can be identified. All seed can be distinguished as being commercial, non-commercial or self-saved seed. Only commercial seed, however, can be further distinguished as being foreign or domestic; or legitimate or illegitimate. If there are differences in the performance in terms of pesticide use and yields between seed from commercial and non-commercial sources, the reason for the difference will not be able to be precisely identified since non-commercial seeds include seeds that are legitimate and illegitimate and seeds that are foreign and domestic. The handling of seeds from commercial and non-commercial channels could also account for the differences.



[a] "Foreign seed" are seed that are produced and marketed by Jidai and that contain genetic material from Monsanto, a foreign life science company.
[b] "Not foreign seed" are seed that are produced and marketed by Biocentury and that contain genetic material from the Chinese Academy of Agricultural Sciences (CAAS).

Fig. 1. Schematic diagram of China's Bt cotton seed industry.

3.3. *Cotton seed adoption in northern China*

Based on our data, it is clear that since China began to commercialize Bt cotton, the nation's cotton farmers have obtained seed from a wide range of sources, including commercial sources. As a matter of historic fact, in the 1980s most farmers in China (or more literally most of the plots of farmers) gained access to cotton seed through traditional, non-commercial channels (or through saving their seed). There were few commercial sources of seed. According to Table 1 (bottom row), the way that China's farmers gain access to seed has changed. By the three year period, 1999–2001, 20 percent of farmers still purchased seed from non-commercial sources; 24 percent still saved they own seed. During this same time, 56 percent (up from nearly 0 in the 1980s) purchased cotton seed on the market from commercial sources. Our data also show that although there are differences across provinces (Table 1, rows 2–6). A large share of farmers in all provinces (minimum of 48 percent of farmers in Anhui to a maximum of 64 percent in Hebei) purchased cotton seed from commercial sources.

There were also differences across provinces in the incidence of saving seed and buying from non-commercial sources (Table 1, columns 2 and 3). Notably, cotton farmers in Anhui and Jiangsu did not save seed at all. Instead, farmers in those provinces bought around half of their seed from traditional, non-commercial sources.

Our data also illustrate that seed from foreign channels dominates seed from domestic channels in the commercial market (Table 2, bottom row). During the years 1999–2001, 74 percent of cotton seed purchased from commercial channels were found to be based on the Monsanto genes. Only 26 percent of the plots of farmers in our sample purchased seed with the CAAS genetic material from commercial sources.

The data by province, however, show that there are differences in the mix of foreign and domestic commercial seed types (Table 2, rows 1–5). Only 33 percent of cotton seed purchased from commercial sources in Jiangsu have the Monsanto gene. Nearly all (98 percent) of the seed in Anhui, however, uses the Monsanto genetic material.

According to information from our survey, there also are large differences across regions and seed types in the incidence of legitimate and illegitimate seed types (Table 3). Overall, when examining the plots planted to seed from commercial sources, 56 percent of the plots are planted with legitimate seed; 44 percent of the plots are planted with illegitimate seed (columns 1 and 2, bottom row). Henan province has the highest incidence of illegitimate seed (83 percent). In contrast, less than 10 percent of the plots of farmers in Hebei and Anhui were planted with illegitimate seed. Curiously, the incidence of illegitimate seed types is higher for domestic commercial seed (66 percent—Table 3, columns 5 and 6, bottom row) than for foreign varieties (36 percent, columns 3 and 4, bottom row). Clearly, our data show that the IPR reform that has occurred to date has not eliminated illegitimate seed types from China's Bt cotton seed market.

3.4. *Seed types, pesticide use and yields*

Descriptive results from our survey also illustrate the possible implications on cotton production from IPR and seed industry

Table 1
Sources of Bt-cotton seed used on the plots of farmers in sample in five provinces of China, 1999–2001 (percent).

Province	Commercial seed companies	Traditional, non-commercial channels	Self-saved seed
Henan	49	30	21
Shandong	57	6	37
Hebei	64	16	19
Anhui	48	52	0
Jiangsu	54	46	0
Total (percent)	56	20	24

Notes: All rows sum to 100. The total number of plots from the sample that farmers plant to Bt cotton is 1319. Of this total, farmers planted 741 of the plots using seed from commercial sources; on 265 of the plots of the plots farmers use seed from non-commercial sources; on 313 of the plots farmers use saved seed from the previous year.

Table 2
Country of origin of Bt-cotton seed from commercial seed companies of sample farmers in five provinces in China, 1999–2001 (percent).

Province	Foreign companies	Domestic companies
Henan	64	36
Shandong	73	27
Hebei	84	16
Anhui	98	2
Jiangsu	33	67
Total (percent)	74	26

Notes: All rows sum to 100. The total number of plots from the sample that farmers plant to Bt cotton when using seed from commercial sources is 741. This table does not include seed from non-commercial sources or self-saved seed.

Table 3
Share of legitimate and illegitimate Bt-cotton seeds of sample households in five provinces in China, 1999–2001 (percent).

Province	Total		Foreign		Domestic	
	Legitimate	Illegitimate	Legitimate	Illegitimate	Legitimate	Illegitimate
Henan	17	83	25	75	5	95
Shandong	40	60	43	57	30	70
Hebei	93	7	93	7	94	6
Anhui	91	9	93	7	0	100
Jiangsu	44	56	88	13	22	78
Total	56	44	64	36	34	66

Notes: All rows sum to 100. The total number of plots from the sample that farmers plant to Bt cotton when using seed from commercial sources is 741. Among these plots, 415 are planted with legitimate seeds and 326 are planted with illegitimate seeds; 349 of the plots are planted with foreign, legitimate seed and 66 of the plots are domestic legitimate seeds; and 200 of the plots are foreign, illegitimate seed and 126 of the plots are domestic illegitimate seeds. This table does not include seed from non-commercial sources or self-saved seed.

reform (Table 4). Above all, there are differences between per hectare use of pesticides on plots that use commercial seed (20 kg/ha) and the use of pesticides on plots that use seed from non-commercial sources (34 kg/ha). At the same time, yields on plots that use seed from commercial channels are higher (3355 versus 3205). From these point estimates, it would appear that if farmers used seed from commercial sources, they would produce cotton more efficiently than if they used seed from non-commercial sources. Based on these descriptive findings, it would appear as if seed industry reform would lead to gains in production efficiency—both lower pesticide use and higher yields.

While this statement about the superiority of seed from commercial sources is true when examining the differences between all types of commercial seed and all types of non-commercial seed, in fact, the reality of China's Bt cotton seed industry is more complicated. When looking at the level of pesticide use and yields of seeds from specific sub-channels of the non-commercial segment of the seed industry (that is, agricultural extension stations—row 8; cotton offices—row 9; and seed production bases—row 10), it is clear that some types (e.g., seed from seed production bases—which on average uses 17 kg/ha of pesticide to produce 3323 kg/ha of cotton) can dominate certain types of seed from the commercial segment of the seed industry (e.g., illegitimate Jidai—which on average uses 23 kg/ha of pesticide to produce 3212 kg/ha of cotton). It is important to note at this point that the numbers from Table 4 only compare pesticides and yields using descriptive statistics. When doing this analysis, we are not holding other factors constant. It is for this reason that we need to perform multivariate analysis (in the next section).

Table 4
Pesticide use and yields of Bt cotton and non-Bt cotton by seed type of sample farmers in five provinces in China, 1999–2001.

	Observations	Pesticide use (kg/ha)	Yield (kg/ha)
Bt seed	1319	23	3294
Commercial seed companies	741	20	3355
Legitimate Jidai	349	20	3553
Illegitimate Jidai	200	23	3212
Legitimate Biocentury	66	15	3299
Illegitimate Biocentury	126	20	3062
Traditional, non-commercial channels	265	34	3205
Ag extension station	131	49	3478
Cotton office	66	21	2543
Seed production base	68	17	3323
Self-saved	313	20	3225
Non-Bt seed	342	70	2700

Notes: Information in this table from a total of 1661 plots planted by our sample farmers. Of this, 1319 of the plots were planted to Bt cotton; and 342 of the plots were planted to non-Bt cotton plots.

In addition to seeing the possible gains from general seed industry reform, Table 4 also allows us to examine possible yield improvements from two additional reforms—allowing foreign companies to compete more in China (a specific seed industry reform agenda item) and increasing the enforcement of IPRs. When we compare legitimate Jidai (with the foreign Monsanto genetic material) to legitimate Biocentury (with the domestic CAAS genetic material), we find that farmers that use the seeds with the foreign genetic material generate higher yields. Likewise, when we compare the illegitimate varieties (illegitimate foreign versus illegitimate domestic varieties), farmers that use foreign seed types also have higher yields. However, the descriptive data do not allow us to see easily if efficiency will rise. Although the yields of the foreign varieties are higher, when farmers use the foreign varieties their pesticide use per hectare also is higher.

A clearer picture is sketched by the descriptive data for the case of IPR reform. Looking at the differences between legitimate Jidai seed and illegitimate Jidai seed; and the differences between legitimate Biocentury seed and illegitimate Biocentury seed, we see that farmers that use the legitimate varieties both use less pesticide and have higher yields. Therefore, based on Table 4, one can expect IPR reform to increase the efficiency of cotton production since the output of cotton producers rises while the use of input does not.

3.5. Hypotheses

Based only on the descriptive findings, it appears as if stronger IPR and seed industry reform might lead to lower pesticide use and higher yields. But we have only looked at simple correlations. It is possible that there are other observable factors that are confounding our results. Therefore, in the next section we use regression analysis to formally test these relationships. To facilitate the test, we use the descriptive findings from our survey data and debates in the literature to generate a set of testable hypotheses that can help us analyze the effect of IPR shifts and seed reform on the performance of farmers. There are three basic hypotheses:

Hypothesis 1 *(Effect of strengthening IPRs).* There are legitimate and illegitimate seeds that are related to two different seed companies (Jidai and Biocentury). The presence of illegitimate seed in our paper is symptomatic of a weakness in China's IPR system. *Hence, it is expected that legitimate seed would use less pesticide and generate higher yields than illegitimate seed.*

Hypothesis 2 *(Effect of seed industry reform).* There are varieties sold by seed companies (Jidai—legitimate and illegitimate; Biocentury—legitimate and illegitimate; and other seed companies that sell unapproved varieties). There are also varieties sold by non-commercial entities other than seed companies—the agricultural extension system; the cotton office; and seed production bases (henceforth, traditional channels). The presence of traditional channels in our paper is symptomatic of incomplete reform. *Hence, it is* *expected that seed from commercial channels would use less pesticide and generate higher yields than seed from traditional, non-commercial channels.*

Hypothesis 3 *(Additional effect of seed reform).* If seed reform were to allow more foreign varieties to penetrate China's seed market, it is expected that Bt cotton yields would rise. However, the effect on efficiency is ambiguous since if seed reform were to allow more foreign varieties to penetrate China's seed market, the use of pesticide on Bt cotton could rise.

4. Data and multivariate approach

Information on seed types in China's Bt cotton industry and the benefits and costs of Bt cotton that have been enjoyed/borne by farmers are measured with data that we collected ourselves. The data set covers 282 households that produced cotton in villages that were producing Bt cotton in 1999, 407 households in 2000 and 366 households in 2001. These data were collected in five cotton producing provinces in northern China (Hebei, Shandong and Henan) and eastern China (Jiangsu and Anhui). During the three years of the survey (which to the extent possible surveyed the same households over time) also collected data on 1661 plots of the sample households, which will allows us to assess the benefits and costs for different Bt cotton varieties.

The survey instrument for each household included a number of different blocks. First, we collected the information that was used to identify the type of seed used on each plot (discussed in the previous section). Another section was used to elicit information about cotton inputs and output. These data were collected by plot. There also were sections that covered the basic information of the household—the characteristics of the farm household, household head and the nature of the farm itself.

4.1. Multivariate framework

To understand the net effect of seeds from different sources (and test our three hypotheses), we adopt a multivariate production function approach using the pooled data (for three years) from five provinces. Our ultimate objective is to estimate the *net* effect on farm households of their Bt cotton seed adoption decisions. The basic form of the regression is to include a measure (dummy variable) for a particular type of seed (e.g., seeds from different sources or different types of seeds, e.g., legitimate versus illegitimate; commercial versus non-commercial; foreign versus domestic) in one of two equations: one for explaining the use of pesticides and the other for explaining yields.

$$\text{Pesticide use} = a_0 + a_1 \times \text{Seed type} + a_2 \times Z + u_1 \quad (1)$$

$$\text{Cotton yield} = b_0 + b_1 \times \text{Seed type} + b_2 \times Z + u_2 \quad (2)$$

Testing the three hypotheses will require us to use different combinations of seed type variables. To test Hypothesis 1, we need to include dummy variables representing measures of legitimate and illegimate varieties for each type of seed (foreign and domestic). In other words, we need to include four dummy variables (Legitimate Jidai = 1 if the seed is a legitimately from Jidai and contains Monsanto genetic material and zero otherwise: Illegitimate Jidai; Legitimate Biocentury; Illegitimate Biocentury). To test Hypothesis 2, we need to combine all of the commercial seed types into a single indicator variable (*Legitimate Jidai + Illegitimate Jidai + Legitimate Biocentury + Illegitimate Biocentury = Commercial Seed*) and to combine all of the non-commercial seed types into a single variable (*Ag Extension Station + Cotton Office + Seed Production Base = Non-Commercial Seed*). Finally, to test Hypothesis 3, we combine the legitimate and illegitimate seed types into a single indicator variable to make a single foreign commercial seed indicator variable (*Legitimate Jidai + Illegitimate Jidai = Jidai Seed*) and to make a single domestic commercial seed indicator variable (*Legitimate Biocentury + Illegitimate Biocentury = Biocentury Seed*).

In order to isolate the effect of the seed types on pesticide use and yields, we needed to hold the effect of household and farm characteristics constant. In the estimation of the pesticide use we include measures of *household characteristics* (*Age* and *Education Level* of the household head in years; whether or not anyone in the household was a *Village Leader* or received training the use of Bt cotton—*Bt Cotton Training*) and a set of *other factors* (dummy variables for *Year* effects; *Provincial* effects; and *Weather* effects—which equal 1 if farmers stated that their communities/fields were abnormally affected by drought or floods or 0 if not). In the yield equation, we include the *same* household characteristics and other factors that were included in the pesticide use equation estimation. In addition, in the yield equation we also included measures of conventional inputs that farmers applied to their cotton crop (*Labor* in days per hectare; *Fertilizer* in kg/ha; and *Other Inputs* in yuan/ha).[1]

While conceptually our approach is fairly straightforward, in the course of the analysis we have to address several statistical complexities. First, to identify the yield effects of Bt seeds and pesticide use, traditional production analysis is not appropriate, since Bt seeds and pesticides do not act like traditional, yield-increasing inputs. Instead, we use a damage control model that accounts for the way that insect-resistant seeds and pesticides abate the damage of insects (Lichtenberg and Zilberman, 1986; Huang et al., 2002b; Carrsco-Tauber and Moffitt, 1992; Babcock et al., 1992; Saha et al., 1997). Second, even using a damage control function, the estimation is complicated by the fact that pesticide use is determined simultaneously with yields. In econometric terms this means there is a possibility that the coefficient on the pesticide variable in the damage-abatement production function is subject to endogeneity-induced bias. Consequently, in estimating the two equations we need to rely on a two-stage, instrumental variable (TSLS) approach. As in Huang et al. (2002b), we use two variables, one measuring pest pressure (*Perception of Yield Loss*) and the other measuring *Pesticide Price*, to identify pesticide use.[2]

Finally, in order to control for other factors that might affect pesticide use or yields (in addition to the source of seed), we also included several other characteristics of the seed that farmers were able to reliably identify during the household surveys. Specifically, we included two dummy variables: one variable is equal to 1 if the seed was a *Coated Seed* (and 0 if non-coated); the other variable is equal to 1 if the seed was a *Hybrid Variety* (and 0 if it was a conventional variety).[3]

5. Impact on productivity

When we use our analytical approach to test the three hypotheses, our specification and econometric framework appear to

[1] For a more comprehensive description of all of the variables, see Huang et al. (2002b).

[2] These two variables can be used as Instrumental Variables (IVs) since they meet the two characteristics of an IV: they should affect the level of pesticide use; but should have no independent effect on yields, except through the use of pesticide. The Perception of Yield Loss is measured by asking farmers the extent of yield loss – stated in percentage terms – that they believe their crop would have incurred had they not sprayed with pesticides (the variable ranging from 0 to 1). The Pesticide Price variable is constructed as the unit value of all of the pesticides applied by the farmer.

[3] Since it is possible that including the Coated Seed variable might lead to an econometric problem that is sometimes referred to as "overcontrolling," we ran the regression models with and without Coated Seed. Essentially, there is no difference in the magnitudes and signs of the coefficients. Therefore, in the paper, we use the regressions with Coated Seed.

Table 5
Regression results for pesticide use and cotton yields in China.

		Hypothesis 1		Hypothesis 2		Hypothesis 3	
		Pesticide use (kg/ha)	Cotton yield (exponential damage control function)	Pesticide use (kg/ha)	Cotton yield (exponential damage control function)	Pesticide use (kg/ha)	Cotton yield (exponential damage control function)
Intercept	1	47.12 (8.36)***	6.03 (18.66)***	48.68 (8.74)***	6.03 (18.71)***	48.70 (8.74)***	6.09 (18.90)***
Perception of *Yield loss* (percent)	2	0.15 (4.47)***		0.14 (4.22)***		0.14 (4.23)***	
Average pesticide *Price* (yuan/kg)	3	−0.19 (5.98)***		−0.19 (5.97)***		−0.19 (5.97)***	
Household characteristics:							
Age (years)	4	0.02 (0.25)	−0.04 (0.71)	0.02 (0.29)	−0.05 (0.79)	0.02 (0.28)	−0.05 (0.83)
Education (years)	5	−1.31 (4.64)***	0.00 (0.13)	−1.33 (4.68)***	0.00 (0.01)	−1.33 (4.68)***	0.00 (0.02)
Village leader dummy	6	1.95 (0.84)	0.08 (1.86)*	1.79 (0.77)	0.08 (1.89)*	1.78 (0.77)	0.08 (1.82)*
Bt cotton training dummy	7	−2.11 (1.38)	0.02 (0.60)	−2.29 (1.50)	0.02 (0.75)	−2.32 (1.51)	0.02 (0.58)
Farm size scale (ha)	8	−13.63 (3.94)***		−13.04 (3.77)***		−13.07 (3.78)***	
Conventional inputs							
Labor input (days/ha)	9		0.03 (0.79)		0.04 (0.92)		0.03 (0.69)
Fertilizer (kg/ha)	10		0.12 (6.98)***		0.12 (6.92)***		0.12 (6.99)***
Other inputs (yuan/ha)	11		0.16 (15.18)***		0.16 (15.09)***		0.16 (15.13)***
Bt seed source							
Commercial seed	12			−34.33 (17.88)***	0.12 (3.35)***		
Jidai seed	13					−34.13 (16.77)***	0.16 (4.18)***
Legitimate Jidai	14	−39.52 (15.38)***	0.25 (5.07)***				
Illegitimate Jidai	15	−29.34 (11.74)***	0.12 (2.63)***				
Biocentury seed	16					−34.76 (14.27)***	0.03 (0.74)
Legitimate Biocentury	17	−40.31 (10.48)***	0.14 (1.90)*				
Illegitimate Biocentury	18	−32.82 (11.82)***	0.01 (0.28)				
Traditional channels (*Non-Commercial Seed*)	19			−32.33 (15.24)***	0.02 (0.41)	−32.31 (15.22)***	0.02 (0.48)
Ag extension station	20	−35.13 (12.81)***	0.00 (0.03)				
Cotton office	21	−30.11 (8.71)***	−0.01 (0.09)				
Seed production base	22	−34.20 (9.03)***	0.18 (2.52)**				
Self-saved seed	23	−32.08 (13.17)***	0.16 (3.39)***	−33.92 (14.29)***	0.16 (3.49)***	−33.90 (14.28)***	0.16 (3.53)***
Coated seed dummy	24	0.88 (0.34)***	−0.01 (0.18)	−4.71 (2.34)**	0.08 (2.06)**	−4.76 (2.36)**	0.07 (1.75)*
Hybrid seed dummy	25	15.62 (6.82)***	0.07 (1.64)*	15.27 (6.73)***	0.08 (1.78)*	15.28 (6.74)***	0.08 (1.81)*
Year dummies							
T2000	26	13.91 (5.66)***	0.13 (3.18)***	14.35 (5.89)***	0.14 (3.36)***	14.29 (5.84)***	0.13 (3.05)***
T2001	27	11.02 (4.09)***	0.37 (8.44)***	11.52 (4.30)***	0.39 (8.87)***	11.46 (4.25)***	0.37 (8.52)***

Table 5 (*Continued*)

		Hypothesis 1		Hypothesis 2		Hypothesis 3	
		Pesticide use (kg/ha)	Cotton yield (exponential damage control function)	Pesticide use (kg/ha)	Cotton yield (exponential damage control function)	Pesticide use (kg/ha)	Cotton yield (exponential damage control function)
Damage control parameter estimates							
C (pesticide parameter)	28		0.42 (2.65)***		0.41 (2.72)***		0.41 (2.74)***
C_1 (Bt variety parameter)	29		3.70 (5.56)***		3.72 (5.61)***		3.72 (5.62)***

Notes: The figures in the parentheses are t ratios of estimates. The model includes 5 dummy variables to control for specific impacts of location (4 provincial dummies) and disaster (flood versus normal). The estimated coefficients for these dummy variables are not included for brevity. The total number of observations is 1661.

*** Significance at 1 percent.

** Significance at 5 percent.

* Significance at 10 percent.

perform well in the estimations of both equations. In the Ordinary Least Squares versions of the pesticide use and yield equations (not shown for brevity), the R-squares measures of goodness of fit were about 0.3, levels—common for farm-level production analysis. The signs on the coefficients of the control variables in both the pesticide use and yield equations also are mostly as expected when we use our TSLS, damage-abatement approach (Table 5). For example, in the pesticide use equation (column 1), the *Perception of Yield Loss* variable indicates that farmer increased pesticide use as pest pressure rose (row 2). In contrast, the negative coefficient on the *Pesticide Price* variable means that higher pesticide prices dampened the demand for pesticide (row 3). *Farm Size* also has negative sign in the pesticide use variables indicating that there were scale economies in the use of pesticides. In the yield equation (column 2), the coefficients on the variables measuring traditional inputs are all positive and their magnitudes are reasonable (Putterman and Chiacu, 1994).

5.1. *Hypothesis 1 (Legitimate versus Illegitimate)*

More importantly, our analysis allows us to test Hypotheses 1–3 by identifying the potential impact of enforcing IPRs and reform of the seed industry on Bt cotton pesticide use and yields (Table 5, column 1).[4] The potential effect of IPRs (Hypothesis 1) can be analyzed by looking at the differences between *Legitimate* and *Illegitimate Jidai* and *Biocentury* varieties. If IPRs were enforced, the illegitimate seed would not be available and more farmers would be using the legitimate seed. According to the multivariate analysis, when farmers used either type of legitimate seed (Legitimate Jidai or Biocentury), pesticide use fell (when compared to non-Bt cotton) from between 39.52 and 40.31 kg/ha (rows 14 and 17). When using the illegitimate seed (either Illegitimate Jidai or Biocentury), the fall in pesticide use is less (29.34 and 32.82 kg, rows 15 and 18) than when farmers used legitimate varieties. Using a Wald Chi-square test to measure the statistical difference between the coefficients on the Legitimate and Illegitimate Jidai variables (that is, line 14 versus line 15) and between the coefficients on the Legitimate and Illegitimate Biocentury variables (that is, line 17 versus line 18), we find that even after holding all other factors constant, the use of pesticides on plots planted with legitimate varieties is lower than the use of pesticides on plots planted with illegitimate ones (Table 6, column 1, rows 1 and 2). In other words, if IPR regulations had been effective in keeping out unauthorized varieties that were being sold as Jidai or Biocentury varieties, the use of pesticide by farmers would have been less.

The effect of enforcing IPRs becomes even clearer when looking at the yield equations (Table 5, column 2). The yields of the legitimate Jidai varieties were 25 percent above those of the baseline conventional varieties; the yields of illegitimate Jidai varieties were only 12 percent more (rows 14 and 15). Statistical tests show that the two coefficients are statistically different (Table 6, column 2, row 1). The same was true in the case of the Biocentury varieties of Bt cotton (rows 17 and 18). The yields of legitimate varieties were 14 percent more than those of conventional varieties; at the same time, those illegitimate versions of the Biocentury varieties were not statistically different from conventional varieties. From an efficiency point of view, in the case of both Jidai and Biocentury, legitimate seeds both outperformed illegitimate ones. While pesticide use fell, yields rose (or at least were no lower). Therefore, we cannot reject Hypothesis 1.

5.2. *Hypothesis 2 (Commercial Seed versus Non-Commercial Seed)*

Our results also suggest that the reform of seed markets also would improve the performance in terms of efficiency of Bt cotton seed (Hypothesis 2—Table 5, columns 3 and 4; Table 6, row 3). While the point estimates of the reductions of pesticide use are nearly the same when using Commercial Seed (−34.33, row 12) or Non-Commercial Seed (−32.33, row 19), the yield gains of Commercial Seed (12 percent greater than conventional varieties of cotton) are greater than Non-Commercial Seed (statistically insignificant). Although we cannot identify why seed purchased from commercial channels make farmers more technically efficient than when they use seed from non-commercial channels, clearly reforming the seed industry in the past has opened up

Table 6
Wald (χ^2) test statistics for statistical testing of main hypotheses.

	Pesticides use	Cotton yield
Hypothesis 1: Legitimate versus Illegitimate Seed (test of IPR reform)		
Legitimate Jidai = Illegitimate Jidai	12.31***	5.18**
Legitimate Biocentury = Illegitimate Biocentury	3.06*	2.39
Hypothesis 2: Commercial Seed versus Non-Commercial Seed (test of seed industry reform)		
Commercial Seed = Non-Commercial Seed	1.09	8.65***
Hypothesis 3: Foreign versus Domestic (test of seed industry reform)		
Jidai seed (Foreign) = Biocentury seed (Domestic)	0.09	9.65***

Notes: ***, **, * denote significance at 1%, 5% and 10%, respectively.

[4] In equations not shown here Bt reduced pesticide use by about 35 kg/ha using the complete sample of the three years and five provinces in our sample. See Huang et al. (2002b) for disaggregated analysis.

a channel for seed through which higher quality seed has been flowing.[5]

5.3. Hypothesis 3 (Foreign Seed versus Domestic Seed)

Our results also suggest that the reforms of commercial seed markets which would open up competition/entry to foreign seed would also improve performance in terms of efficiency (Hypothesis 3—Table 5, columns 5 and 6; Table 6, row 4). While the point estimates of the reductions of pesticide use are nearly identical when using Jidai (foreign) Seed (−34.13, row 13) or Biocentury (domestic) Seed (−34.76, row 16), the yield gains of Jidai Seed (16 percent greater than conventional varieties of cotton) are greater than Biocentury Seed (statistically insignificant). One lesson from these findings is that China's decision to allow foreign seed companies into the nation's cotton industry appears to have benefited the sector in terms of technical efficiency. These field level efficiency gains almost certainly are why estimates of aggregate levels of total factor productivity gains for China's cotton sector rose sharply after 1995 (Jin et al., 2008).

6. Conclusions

This paper reviews the changes that have taken place in the laws and policies that officials use to manage China's plant biotechnology sector—IPR legislation and seed industry reforms. In reviewing China's IPRs and seed industry reforms, the paper has identified shortcomings in the current systems. Despite the weaknesses, seed firms are developing new varieties at a rate greater than in the past. These investments, however, are still extremely small compared to those of private seed firms in many OECD countries or other developing countries (Pray and Fuglie, 2001).

Using data collected from farmers in China, our regression analysis not only confirms what earlier studies have shown—Bt cotton uses much less pesticide and has higher yield when compared to conventional, non-Bt cotton. It also shows that legitimate seed from commercial sources provides more benefits to farmers than illegitimate seed. We also found that seed that came through commercial seed channels was technically more efficient on the plots of farmers than seed that came through traditional, non-commercial channels. Foreign seeds (allowed into the country by past seed industry reform) outperformed domestic seed. In other words, our results suggest that the government should continue to consider pushing forward its IPR reform and enforcement as well as seed industry reform. If so, according to our results, the production efficiency of cotton should rise on the plots of farmers.

Alternatively, there may be another set of policy suggestions that are implied by the results that do not require the government to increase its efforts in implementation and enforcement of IPRs and seed industry reform. It could be that such efforts are difficult to implement in practice and the costs of implementation and enforcement (which are ignored in our analysis) could offset all or part of the benefits. If the main reason that farmers do not all use the most effective types of commercial seeds, legitimate Jidai and legitimate Biocentury, is that they did not know any better, it could be the most appropriate response to this study's findings is to publicize the results. If farmers (and local officials) know the benefits of using legitimate Bt cotton seeds, without any additional regulation, it is possible that they would adopt these varieties in higher numbers.

[5] One caveat is needed, however. From Table 5, columns 1 and 2, it is clear that not all Non-Commercial Varieties are the same. Seed from different Non-Commercial sources (Ag Extension Station; Cotton Office; Seed Production Base) lead to different levels of reduction in pesticide use (e.g., seed from the Ag Extension System gives the largest reductions; seed from Seed Production Bases lead the highest yield rises).

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