



The Spread of Illegal Transgenic Cotton Varieties in India: Biosafety Regulation, Monopoly, and Enforcement

BHARAT RAMASWAMI
Indian Statistical Institute, New Delhi, India

CARL E. PRAY
The State University of New Jersey, USA

and

N. LALITHA*
Gujarat Institute of Development Research, Ahmedabad, India

Summary. — Plantings of unapproved genetically modified seeds (GM) happen in many developing countries including Brazil, China, and India even though the law does not permit it. Is regulation impossible and what does that imply for safe use of GM seeds? This paper examines these questions in the case of unapproved GM cotton plantings in Gujarat, India. We find that enforcement was possible and that there are no obvious bio-safety implications. The popularity of unapproved seeds (confirmed by contingent valuations), the de-facto intellectual property of legal seeds and the federal polity of India contributed to non-compliance. This could matter for future innovations.

© 2011 Elsevier Ltd. All rights reserved.

Key words — biosafety regulation, genetically modified seeds, transgenic varieties, Bt cotton, India, Asia

1. INTRODUCTION

The commercial release of transgenic plants and that of foods derived from it requires approval from biosafety regulators who are charged with protecting the environment and consumers from potentially harmful new organisms. This is quite unlike plant varieties that are the outcome of conventional plant breeding, which are either not regulated or at best tested for agronomic performance. As a result, the introduction of transgenic products has required the establishment of new institutions, risk protocols, and legal structures.

Biosafety regulations can also have unintended consequences. During 2002–06, only one company in India—MAHYCO Monsanto Biotech (MMB)—had the permission to sell the Bt gene implanted in cotton. This gene protects cotton plants against their major pest in India, the bollworm. The regulations in effect gave MMB a monopoly on the sale of legal Bt.

However, despite the resources and the time invested in promulgating new laws and setting up new institutions for biosafety, illegal transgenic varieties are found in many developing countries, such as Brazil, China, and India (da Silveira & de Carvalho Borges, 2007; Fukuda-Parr, 2007; Huang, Hu, Rozell, & Pray, 2007; Ramaswami & Pray, 2007). These seeds are illegal because they have not gone through biosafety regulation despite being genetically modified. Estimates suggest that in some years the bulk of the area planted in transgenic crops in developing countries was in fact planted with illegal varieties. The failure to enforce biosafety laws is widespread and demands explanation.

One view is that infirmities in regulation demonstrate a lack of capacity for enforcement of bio-safety laws, which is a good reason to delay the commercialization of transgenic plants.

(Sahai, 2005). This was also the basis of a public interest law suit in India that called for a moratorium on field trials of transgenic plants because of possibilities of contamination from improperly supervised trials (Rodriguez *vs.* Union of India, 2005). Another view is that the very large number of small-scale farmers in developing countries poses great challenges for enforcement and so “command-and-control” approaches to regulation are unlikely to work (Nuffield Council, 2004).

But what if neither is the case? What if it was possible for governments to control illegal varieties, but they decide not to do so? Then the question becomes why does not the government enforce these laws? Why do they apparently give up on biosafety? In the Indian case, the biosafety implications are possibly not that compelling because the illegal seeds are simply “underground” versions of legal seeds carrying the gene and trait which went through extensive biosafety testing in India and elsewhere.

However, illegal seeds clearly erode the profits of the legal suppliers of transgenic seed. The firm responsible for the innovation receives little or no benefit from the diffusion of the illegal seeds. By contrast, because of licensing agreements, the firm receives a technology fee from every packet of legal transgenic seeds that contains the trait in question. The enforcement of biosafety regulations, therefore, contains the same essential dilemma as that of intellectual property rights

* The USDA Emerging Markets Program provided financial support for this study. We thank Maurice Landes, Robert Tripp, and anonymous referees for many useful comments. The contribution of the survey team led by Ila Mehta is gratefully acknowledged. Final revision accepted: March 1, 2011.

(IPRs)—how does one preserve the incentives for innovators without restricting the spread of the innovation? This is clearly a serious issue because if governments cannot or will not prevent the spread of illegal seeds, then companies might decide not to make available newer seeds as they become available in the future.¹

This paper examines these difficulties of regulation in the context of illegal transgenic Bt cotton varieties in India. Based on a survey of cotton growers in Gujarat in 2004, the paper asks three questions. The first question is whether the lack of enforcement is because of obstacles stemming from small-holder agriculture and the large number of growers? Our analysis of government institutions and the nature of hybrid seed production suggests that regulations could have been enforced. If this is so, why was illegal seed allowed? And thirdly, does socially beneficial policy lie in strict enforcement? If not, how can India provide for biosafety and structure incentives for the development and commercial release of new technologies?

2. COTTON HYBRIDS AND BT COTTON

The Indian cotton seed market consists of both self-pollinated varieties and hybrid varieties. The release of improved self-pollinated cotton varieties is an entirely public sector activity. Private investment is absent here because the private sector cannot protect its intellectual property in selling self-pollinated variety seeds. Private investment in plant breeding is directed toward developing hybrid seeds. Although private-bred (or proprietary) hybrids were developed after the success of public-bred hybrids, they now dominate the cotton seed market. Overall, these hybrids account for 70% of all India plantings (Murugkar, Ramaswami, & Shelar, 2007). Maharashtra, Andhra Pradesh, and Gujarat are the leading cotton growing states within India.

As cotton is essentially a self-pollinated crop, the crossing of inbred lines cannot be left to natural pollination processes. In the female line, each individual flower bud is emasculated and pollinated by hand. This has to be done carefully without damaging the other flower parts. The activity is highly labor intensive and requires about 10 times more labor than cotton production (Venkateswarlu, 2003). An alternative and much less labor intensive technique is to use male sterile lines through cytoplasmic male sterility or genetic male sterility. However, most hybrids are produced by hand emasculation methods. Gujarat is the leading state in hybrid seed production, followed by Andhra Pradesh. In 2003–04, nearly 55,000 acres were under cotton seed production in the country out of which 26,000 were in Gujarat (and 14,000 acres in Andhra Pradesh).²

Bt cotton is a departure from conventional plant breeding.³ *Bacillus thuringiensis* (Bt) is a soil borne bacterium toxic to certain insect pests and safe to higher animals. It is widely used as a bacterial insecticide. *Cry* genes from the bacteria determine the action against pests. These have been transferred by genet-

ic engineering techniques to different plants (maize, cotton, vegetables) to confer resistance to pests. Bt cotton offers resistance to an important pest, the American bollworm (*Helicoverpa amigera*), which has developed resistance to all the commonly used insecticides in the country (Kranthi & Kranthi, 2004). In India, the first three Bt cotton hybrids were approved for cultivation in 2002. In subsequent years, many more Bt cotton hybrids have won approval.

Table 1 displays the area under Bt hybrids from 2002 to 2008. During this period the area under all cotton has fluctuated between 8 and 9.5 million hectares. Thus, Bt cotton has diffused rapidly and widely. The table also shows the significant presence of illegal varieties, which outweighed the area under legal seeds till 2005. Illegal seeds, however, continue to be dominant in the state of Gujarat. A recent survey of 200 cotton growers found that 60% of their cotton area in 2007 were under illegal Bt seeds (Lalitha, Ramaswami, & Viswanathan, 2009).

3. DE FACTO IPRS AND MARKET STRUCTURE

The first genetic event to be approved by the biosafety regulator was the insertion of a Bt gene (*cry1Ac*), belonging to Monsanto, in three cotton hybrid cultivars (MECH 12, MECH 162, MECH 184) belonging to the Indian seed company Mahyco. This event was commercialized by a joint venture called Mahyco Monsanto Biotech (MMB), which is equally owned by the two partners. After backcrossing was done, the first biosafety tests were done in 1997. The approval for commercial release came five years later in 2002. The hybrids were approved for cultivation in southern, western, and central India for a period of 3 years. In 2004–05, the government granted permission for the release of several other hybrid varieties of Bt cotton.

MMB has derived a measure of protection for its gene through bio-safety laws. The gene itself has not yet been patented in India.⁴ However, as bio-safety approvals are obtained for the composite of the gene and the germplasm, hybrids that incorporate MMB's gene but do not go through the bio-safety process are illegal. While this has not stopped the diffusion of illegal *Bt* seeds, it has led the seed companies wishing to work within the law (which includes all the established firms with branded products) to either deal with MMB or consider an alternative *Bt* strategy. At this point, most of the firms have chosen to license the *Bt* technology from MMB. Although MMB does not hold an Indian patent over its gene, the regulatory authorities are unlikely to approve a Bt hybrid that incorporates an unlicensed version of the MMB gene.⁵ Thus, the biosafety regulation creates "de facto" intellectual property rights for the legal Bt cotton.⁶

Biosafety regulatory processes also constitute an entry barrier for new genes. Pray, Bengali, & Ramaswami (2005) report the compliance costs of early products that went through the regulatory system. These are MMB's first *Bt* cotton hybrids and Bayer's GM mustard hybrid. Compliance costs were

Table 1. Diffusion of Bt cotton (million hectares)

	2002	2003	2004	2005	2006	2007	2008
Area under approved Bt hybrids	0.03	0.09	0.5	1.3	3.8	6.2	7.6
Area under illegal Bt cotton	0.04	0.25	0.8	2.0	1.7	1.2	–

Note: The area under approved Bt hybrids is sourced from various publications of the International Service for the Acquisition of Agri-Biotech Applications, www.isaaa.org. The areas under illegal seeds are our estimates based on estimates offered by seed industry representatives, industry publications, and newspaper accounts.

found to be high for MMB and Bayer. In the case of MMB, pre-approval costs were about US\$1.8 million, of which \$300,000 was spent on field trials. The largest value of cotton seed sales from any single firm is in the neighbourhood of \$30 million per year.

Bayer's compliance costs were even higher, in the range of \$4–\$5 million. The genes used to produce hybrid mustard have been used in canola to produce hybrid canola cultivars in Canada and the U.S. where they have cleared the bio-safety regulations. However, use of these genes in mustard has not been commercialized anywhere in the world. Because of continued costs, uncertainty about whether GM mustard would ever be approved and the market potential for this product, Bayer decided not to continue trying to commercialize it in India. Because of the time and money required to acquire approval, the regulatory system serves as a barrier to entry by firms other than those that can fund regulatory compliance and have the capacity to negotiate and smoothen regulatory risks.^{7, 8}

With *Bt* cotton, the seed industry encompasses a seed market as well as a technology market. Until 2006, the technology market consisted of only one supplier—MMB, which has licensed its *Bt* gene to almost all of the leading cotton seed companies. For a seed company, licensing *Bt* and developing a *Bt* hybrid means a substantial hike in R&D investment. However, that has not constituted an entry barrier as more than 20 firms have licensed *Bt* genes from MMB. While non-MMB *Bt* genes have entered the market in 2006 in very small amounts, their ability to compete in the technology market is handicapped by the first mover advantage of MMB. As farmer preferences have shifted to *Bt*, seed companies have scrambled to tie up with MMB. As these companies have some of the best performing hybrids in the country, the “lock-in” with Monsanto genes means that the alternative genes would find it hard to find a market.

MMB did exercise its monopoly power as long as it could. Prior to the 2006 season, it priced *Bt* hybrid seeds to be four times that of non-*Bt* hybrids. On the other hand, seed production costs do not differ between *Bt* and non-*Bt* hybrids. In 2006, the Andhra Pradesh government cited the high prices of *Bt* seeds (relative to non-hybrids and relative to *Bt* cotton seeds elsewhere in the world) as evidence of anti-competitive pricing and imposed price controls that halved the price that MMB was able to charge. Other state governments followed.

Despite high prices, most research papers have found that growers have gained substantially by growing *Bt* cotton (Bambawale *et al.*, 2004; Bennett, Ismael, Kambhamapati, & Morse, 2004; Naik, Qaim, Subramanian, & Zilberman, 2005; Qaim, 2003). Using conservative estimates thrown up by this literature, Ramaswami and Pray (2007) conclude that growers received about two-thirds of the gains from *Bt* cotton while the remainder went to the seed company.⁹

From the point of view of public policy, MMB's market power in the cotton seed market, facilitated in no small measure by the government's biosafety regulatory requirements, may, therefore seem an acceptable trade-off. While competitive pricing would generate more gains for growers and also greater diffusion, it would also mean that MMB receives no rewards for its technology, severely jeopardizing incentives for future product development from MMB and other potential technology suppliers.

4. THE DIFFUSION OF ILLEGAL SEEDS

The approval to the MMB varieties was preceded by the discovery of an unauthorized *Bt* cotton hybrid in farmers' fields

at the end of 2001 in Gujarat. The illegal seed was NB 151, a variety registered with the Gujarat government as a conventional hybrid. The variety belonged to Navbharat Seeds, a firm based in Ahmedabad. Later investigation confirmed that the *Bt* gene in NB 151 is the Cry 1 Ac gene developed by Monsanto and used in the legally approved varieties.

The government barred Navbharat Seeds from the cotton seed business and prosecuted it for violating biosafety laws. Yet despite this, the multiplication and distribution of illegal varieties continued to spread. As can be seen in Table 1, illegal seed plantings diffused rapidly and covered an area larger than that under legal seed until 2005. However, illegal seeds are geographically concentrated in Gujarat and can be found to a lesser extent in Punjab and Andhra Pradesh.

Authors like Herring (2007) and Shah (2005) have emphasized the limits of legal monopolies in seeds. They suggest that farmers always have the ability to make “gray-market” versions of the legal seed. Herring's characterization of the proliferation of illegal *Bt* cotton seeds in Gujarat is evocative. “Neither duped nor passive puppets of multinational monopolists, they (cotton farmers) are continuing the primordial struggle of agriculture against insects, with a new weapon. Their techniques continue traditions of seed saving, seed exchange, and seed experimentation that have historically produced better crops and better incomes.” Herring sees farmers as possessing “stealth” strategies, resulting in an “opportunistic agrarian anarcho-capitalism among farmers themselves” that functions “without property or biosafety.”

If farmers freely experiment, adapt, and exchange seeds, policing the diffusion of those seeds that violate property rights or have not received biosafety clearance is difficult. Herring quotes a government official to say, “It is impossible to control something at this large a scale. When we go to the fields, we become targets for trying to take away a beneficial technology from farmers.” While this statement admits the practical difficulties of enforcing the prohibition against illegal seeds, it also acknowledges their popularity among farmers implicitly questioning why such seeds should be illegal in the first place.

What are the “stealth” strategies that farmers use? In the Indian case, the illegal *Bt* cotton seeds are hybrids.¹⁰

As noted earlier, the seeds that are saved from a crop planted with the hybrid seed (the F2 generation) are a genetic mixture and do not have the same hybrid vigor and resistance properties as the first generation hybrid seed. Further multiplication reduces performance even further. So growers desirous of getting maximum yields from their crops necessarily have to plant first generation hybrid seed. The typical strategy of multiplying and saving seeds does not work with hybrids which is, of course, the reason why the private seed industry invests in hybrid seed development (as opposed to varieties which can sustain performance across many generations). As we shall see, planting F2 seeds is an important “stealth” strategy for farmers in Gujarat. However, a considerable proportion of area is planted as well with illegal F1 seeds. Where do farmers get these seeds?

As we saw earlier, production of hybrid seed requires access to parent lines and the experience and skill in crossing them manually. Seed companies typically contract production of hybrid seed to select seed growers. The contract fixes a price that will be paid to growers. The company supplies the parent seed and agrees to buy back the seed from the crossings at a price that is fixed by the contract. Growers receive an advance usually around a fifth of the price of the seed. Gujarat as a leading center of hybrid cotton seed production in India has many experienced growers skilled in producing hybrid seed.

It is, however, a specialized task requiring more resources (ten times more labor and five times more capital) than normal cotton cultivation and growers hire labor (often children and young women) for cotton seed production (Venkateswarlu, 2003).

If this is the picture for legal hybrid seeds, could it be vastly different for illegal hybrid seeds? Would they not require some organization in terms of seed growers, capital, and most importantly a network for distributing seeds? Indeed, we did observe several seed companies that were active in selling and producing illegal seeds. Our interviews with farmers indicate that they obtained the seeds from “other growers” or seed dealers. The “other growers” that supplied the seeds were not the producers of the seeds but were sales agents of the producers. Our fieldwork suggests that illegal Bt cotton seed production and sales are not controlled by a single agent but neither is it the outcome solely of individual stealth strategies. Rather the seed is produced through a loose network of seed companies, producers, and their agents many of whom were former contract seed growers for NavBharat. It is not clear how many agents in this network obtained the NavBharat inbred parental lines—however, ownership of it seems fairly dispersed. As a result, there has been wide experimentation and the male parent (with the Bt gene) has been often crossed with different female lines producing a broad range of varieties often very well adapted to local conditions. Although the seed producers are careful not to advertise on a wide scale, the illegal seeds are known to growers through locally known brand names or as NB 151.

From fieldwork in one district of Gujarat, Shah (2005) finds that illegal seed sales happen through two channels. The traditional channel is through companies that produce hybrid seeds through contract production.¹¹ But Shah also finds that seed multiplication and sales also occur through farmers and that parent Bt male seeds were available in the market.¹² However, even here Shah cites the importance of access to skilled labor (seasonal migrant labor in this case) for seed production. Shah also finds that illegal seeds move from seller to buyer through social networks that offered trust to the parties in the transaction.

The underground seed economy does not seem anarchic or devoid of organization. Hybrid seed production demands specialization that immediately implies a structure for their distribution. The traditional strategies of saving seed and modifying them to local conditions do not work with hybrid seeds. As Roy, Herring, and Geisler (2007) demonstrate, farmers actively evaluate and experiment with different types of cotton seeds, whether with respect to pest resistance or with respect to their soil and water endowments. The point is that the diffusion of illegal seeds rested not so much on individual stealth strategies but on a stealth economy to use Herring’s terminology. This economy includes farmers as well as seed growers, seed companies, and distribution agents. The government official quoted by Herring was surely right in suggesting that illegal seeds could not be curbed by penal action against millions of growers. However, seed producers and seed companies are, in comparison, a much smaller and finite number and the problem of enforcement is not as serious as suggested by the government official. The government possesses the information and means to enforce the law.

It is the responsibility of state governments to prosecute violations of biosafety law. Through India’s seed laws, the state governments have wide coercive powers to raid, inspect, and seize seed supplies except for farmer-to-farmer exchange of seeds. This loophole has allowed the state government to claim ignorance of the extent of illegal plantings. For their part, ille-

gal seed sales try to soften their challenge to the law by taking care to mask the seed sales as seed exchange. The illegal seeds are often sold loose in packets without a company seal and without a bill of purchase. If enforcement is not the issue, why has the state government chosen to turn a blind eye to illegal seeds? Our hypothesis is that the illegal seed is highly profitable to farmers, that they see environmental and health benefits and as a result state governments have strong political incentives to do nothing.

5. DATA ON THE IMPACT OF ILLEGAL AND LEGAL BT COTTON ON FARMERS

None of the published studies of Bt cotton have separated the impact of legal and illegal Bt cotton on farmers. So we set out to collect this type of data in 2004. Our data come from a questionnaire administered to a stratified survey of 160 randomly picked cotton growers in the districts of Rajkot, Bhavnagar, Bharuch, and Vadodara. In each district, four sub-administrative units (the *talukas*) were chosen randomly and within each *taluka*, two villages were chosen randomly. In each village, a listing of cotton growers was made out of which five growers were picked randomly. The survey was conducted during April–May of 2004 and the information collected pertain to the cotton season of 2003–04 which in some cases ended as late as March 2004.

Nearly three quarters of the sample growers of the sample grow Bt. Most of these Bt growers (82%) do not grow any other type of cotton. As many as 57% of the Bt growers planted Bt for the first time in the 2003–04 season. As for the non-Bt users, about 20% of them used Bt in the past. The rate of entry into the ranks of Bt growers is far higher than the exit from these ranks. The response to a question about when in the past growers began to plant Bt revealed that significant use of Bt cotton began from 2002 onwards. In terms of number of growers, illegal Bt dominates Bt plantings. 71% of Bt growers grow illegal Bt only; 13% grow the legal MMB Bt varieties only; while the remainder 16% use both types. Eighty five percent of cotton farmers spray pesticide. Most of the pesticide application is by manual means and often uses family labor.

Almost all farmers in the sample have heard about Bt cotton. Media, government extension services, company propaganda, and seed sellers tend to be unimportant sources of information relative to fellow farmers, neighbors, and friends. Thus, the formal information sources are not as important as the informal network. Consistent with this, very few growers report a visit by government officials or company representatives.

6. VARIETAL-WISE COMPARISONS

We have area, yield, and seed price information for each cotton variety that is grown by the farmers in the sample. Our sample of 160 farmers grew 50 distinct cotton varieties and some farmers grew more than one variety.¹³ The distribution of area under the principal cultivars is in Table 2. As noted earlier, illegal Bt varieties go by different names and include F2 generation hybrid seed. Indeed, Navbharat F2 seed is widely used—on as much as 20% of cotton area.

In our sample, 55% of the cotton area is planted with Bt varieties—illegal seeds are predominant, accounting for 43% of area (Table 3). While Bt cotton plots tend to be smaller than non-Bt plots, the proportion of area that is irrigated is signif-

Table 2. *Distribution of principal cotton varieties in survey*

Variety name	Category	Proportion of area
Sanju hybrid	Non-Bt Hybrid	1.41
Shankar 6	Non-Bt Hybrid	2.32
Shankar 8	Non-Bt Hybrid	5.95
Desi Gujarat 23	Desi	5.71
Desi	Desi	18.76
Sarathi	Illegal Bt hybrid	1.20
unknown Bt	Illegal Bt hybrid	2.96
Rakshak	Illegal Bt hybrid	3.44
NB 151	Illegal Bt hybrid	9.49
NB 151—F2	Illegal Bt hybrid	20.34
Mahyco 162	Legal Bt hybrid	2.43
Mahyco 12	Legal Bt hybrid	7.35
All of the above		81.36

Source: Our survey.

Table 3. *Group comparisons: land and seed source*

	Non-Bt	Legal Bt	Illegal Bt
As % of all cotton area	45	12	43
Size of cotton plot (acres)	7.85	4.45	5.25
Proportion of Area Irrigated	0.67	0.93	0.82
Proportion of area that is good soil quality	0.55	0.66	0.5
Medium soil quality	0.4	0.34	0.47
Bad Soil quality	0.05	0	0.03
Proportion of are that has seed sourced from seed dealer	0.42	0.82	0.17
Proportion of area that has seed sourced from state seed corporation	0.19	0.01	0.03
Proportion of area that has seed sourced from other farmers	0.14	0.11	0.56
Proportion of area that is planted with saved seed	0.07	0	0.01
Proportion of area that is planted with seed from other sources	0.15	0.06	0.23

Source: Our survey.

icantly higher. However, there is no significant difference in soil quality. Table 3 also shows that legal seeds are almost entirely procured from seed dealers while non-Bt seeds are obtained from a variety of sources that include seed dealers (the most important source) but also from state seed corporation, other farmers, and self-saved seed. For illegal seeds, other farmers are the most important source. As discussed earlier, leading growers in a locality often tend to be the agents of distribution of illegal seeds.

Table 4 compares household size, its composition, age profile, and education across growers of non-Bt seeds, legal Bt

seeds, and illegal Bt seeds.¹⁴ This table demonstrates that there are no significant differences in terms of household demographic characteristics between the growers of different kinds of cotton varieties.

Table 5 compares input use and yields across a five fold classification of cotton varieties—*desi* varieties,¹⁵ non-Bt hybrids, legal Bt hybrids, illegal Bt hybrids (excluding, however, F2 seeds), and illegal Bt F2 seeds. As expected, seed costs are the highest for legal Bt seeds and the lowest for *desi* varieties. The illegal Bt seed (excluding F2 seeds) costs as much as 77% of the legal Bt seed and they are more expensive than non-Bt

Table 4. *Grower comparisons: household demographics*

	Non-Bt	Legal Bt	Illegal Bt
Household Size	5.29	5.79	5.25
# Male adults	1.9	2	2.04
# Female adults	1.66	1.65	1.67
Proportion of male adults with ≤ 3 yrs of education	0.04	0.03	0.05
Proportion of male adults with > 3 yrs and ≤ 8 yrs of education	0.26	0.27	0.26
Proportion of male adults with > 8 yrs and ≤ 12 yrs of education	0.45	0.5	0.42
Proportion of male adults with > 12 yrs of education	0.25	0.2	0.27
Proportion of female adults with ≤ 3 yrs of education	0.07	0.05	0.08
Proportion of female adults with > 3 yrs and ≤ 8 yrs of education	0.38	0.41	0.34
Proportion of female adults with > 8 yrs and ≤ 12 yrs of education	0.27	0.24	0.26
Proportion of female adults with > 12 yrs of education	0.29	0.31	0.32
Age of farmer (years)	45.43	45.88	47.7
Years of education of farmer	10.31	8.76	10.18

Source: Our survey.

Table 5. *Plot comparisons: input use, yield and price*

Item	Plot type				
	Desi	Non-Bt hybrid	Legal Bt	Illegal F1 Bt	Illegal F2 Bt
Seed cost: rupees/acre	42	609	1489	1148	492
# of pesticide sprays against bollworms	0.64	5.34	4.18	3.24	2.72
# of pesticide sprays against sucking pests	0.54	5.05	5.21	5.51	4.89
# of pesticide sprays against other pests	0.18	2.16	1.76	2.29	1.32
Total # of pesticide sprays	1.36	12.55	11.15	11.04	8.94
Fertiliser cost: rupees/acre	93	2835	4764	2640	1645
Yield (kg/acre)	199	653	999	1148	734

Source: Our survey.

hybrid seed.¹⁶ It is the Bt F2 seeds which are relatively inexpensive and cheaper than the non-Bt hybrid seeds.¹⁷

As remarked earlier, in a competitive market, if there were no monopoly over the Bt technology, the price of Bt hybrid seed would be comparable to the price of non-Bt hybrid seed (assuming that with free entry there are no shortages of preferred seeds).¹⁸ While MMB was the only supplier of legal Bt seeds in 2004, the situation as we described in an earlier section was decidedly murky for illegal seeds. There seemed to be a multitude of suppliers as well as a number of variants of the basic NB 151. Referring to this, Roy *et al.* (2007) commented “In Gujarat, something like the obverse of monopoly is evident in the fields—a rare competitive market.” Yet, despite the competition between the legal and illegal seeds, both cost much more than non-Bt hybrids indicating the market power of the Bt hybrids whether legal or illegal.

This strongly suggests that the market for illegal Bt seeds was not fully competitive. Whether because of the ownership of parent lines or because of the distribution network (and the ownership of “trust” that is necessary to operate it), suppliers of illegal Bt possessed market power.¹⁹ This also confirms that the diffusion of illegal Bt cannot just be due to farmer reproduction and exchange.

Legal Bt cotton growers seem to practice more intensive agriculture than the other cotton growers.²⁰ They use more fertilizer than either the illegal Bt cotton growers or the non-Bt category. As expected, growers spray fewer times against bollworms on Bt cotton fields (whether legal or illegal) than on non-Bt cotton. Also, there is no difference between the groups with regard to sprays against other insects which confirms similar findings in Qaim (2003), Bennett *et al.* (2004).

Average yields of Bt cotton, whether legal or illegal, whether F1 or F2, are significantly higher than yields of non-Bt hybrids. The yield advantage of legal Bt hybrids is about 50%, while that of illegal F1 Bt hybrids is over 70%. Even the average yield of F2 Bt hybrids is higher than that of non-Bt hybrids by more than 10%. This pattern in yield differences persists even after we controlled for differences in land quality, inputs, and locations. Because of space limitations, we do not report these regressions here.

The tables are revealing about the economics of the choice between non-Bt hybrids and illegal F2 generation Bt seeds. The latter is higher yielding, is a cheaper seed, and needs less pesticide application than the former. In other words, illegal F2 Bt seeds dominate non-Bt hybrids in performance and cost. Similarly, the economics of the choice between legal and illegal F1 hybrids seems quite transparent. While the two variety types have similar yields and thus similar revenues, costs whether for pesticides, seeds, or fertilizers are substantially lower for illegal hybrids. The popularity of illegal varieties is, therefore, not hard to explain. Note that the higher yields

of Bt varieties need not necessarily be due to the Bt trait alone; the popular non-Bt hybrids are the public *sankar* hybrids while the Bt varieties might have a better genetic background.

7. FARMER'S VALUATION OF BT SEEDS: BID DESIGN, AND METHODOLOGY

The above findings are based on data from a single year and its robustness to varying weather conditions and pest infestations is open to question.²¹ In a world where farmers choose between seed alternatives based on what maximizes their returns, the valuation of these seeds by farmers would reflect their cumulative experience and would, therefore, be useful to validate the performance analysis.

Stone (2007) has argued, however, that this need not be the case. From an analysis of seed choices in some villages of Warangal district of Andhra Pradesh, he concludes that seed choices can be driven by fads that have little grounding in considered evaluations of payoffs from various seeds.²² This suggests that it is not just enough to elicit farmer's valuations, but they must be systematically correlated with grower characteristics and technology perceptions if they are to be something more than random noise.

To do this, we undertook parallel contingent valuation exercises for both legal and illegal seeds.²³ For legal seeds (from Mahyco Monsanto), the bid design consisted of an initial question where all growers were asked whether they were willing to use these seeds (for the next season) at the prevailing price of Rs. 1600 per packet.²⁴ If a grower responded in the negative, then, he was offered one of 6 distinct prices (Rs. 1000 to Rs. 1500 in Rs. 100 increments) chosen randomly. Thus, we have three possible responses: Yes; No, Yes and No, No. Nearly 26% of all growers were willing to pay Rs. 1600 per packet. The sub-sample of growers not willing to pay Rs. 1600 were then asked the follow up questions. A key difference from the usual contingent valuation application is that not everything is hypothetical here. In particular, as the legal seed sold at Rs. 1600 for a packet, this price is likely to be fixed in the minds of responders as an upper bound on the willingness to pay. We, therefore, begin, by asking about willingness to pay at Rs. 1600. If the person answers yes, there are no further questions while if the person answers no, he/she receives a second question with a lower bid price.

The survey also posed willingness to pay questions regarding illegal F1 seeds (Navbharat 151 and its variants). This module consisted of two questions corresponding to the usual double-bound contingent valuation methods. The first question asked whether the grower was willing to pay Rs. X for F1 illegal seed where X was randomly varied between Rs. 900 and Rs. 1500 (the randomization was independent of the

random price that confronted the grower in the valuation for legal seeds). If the grower responded negatively, the bid price was dropped to Rs. 800. If the grower responded positively to the first question, the bid price was raised to Rs. 1600.

To determine the correlates of grower’s valuations, suppose that $W_j = \beta x_j + \varepsilon_j$, where W_i is the willingness to pay (WTP) of the i th individual for legal seeds, x_i are the correlates that are observed by the econometrician and ε_i captures the correlates that are not observed by the econometrician. It is assumed that each individual receives a particular ε_i that is drawn from a specified distribution. The goal is to estimate the beta parameters and recover the distribution of WTP. This is done by considering the likelihood of observing the given data of responses. For the legal seeds, the probabilities of the three responses are:

- (a) $\Pr ob(Yes) = \Pr ob(W_j > 1600) = \Pr ob(\beta x_j + \varepsilon_j > 1600) = \Pr ob(\varepsilon_j > 1600 - \beta x_j) = 1 - \Phi(1600 - \beta x_j/\sigma)$ where Φ is the cumulative density of ε .
- (b) $\Pr ob(No, Yes) = \Pr ob(t_j < W_j < 1600) = F(1600) - F(t_j) = \Phi(1600 - \beta x_j/\sigma) - \Phi(t_j - \beta x_j/\sigma)$ where t_j is the bid price offered to the grower in the follow-up question.
- (c) $\Pr ob(No, No) = \Pr ob(\beta x_j + \varepsilon_j < t_j) = \Pr ob(\varepsilon_j < t_j - \beta x_j) = \Phi(t_j - \beta x_j/\sigma)$ From the above, the log likelihood can be formed as

$$\log L = \sum_{j=1}^r \left(\frac{I_1 \ln[1 - \Phi(1600 - \beta x_j/\sigma)] + I_2 \ln[\Phi(1600 - \beta x_j/\sigma) - \Phi(t_j - \beta x_j/\sigma)] + I_3 \ln[\Phi(t_j - \beta x_j/\sigma)] \right)$$

Table 6. Responses to WTP questions

WTP responses	# of growers
<i>Legal seeds</i>	
WTP > 1600 (Yes)	41
WTP > t (No, Yes)	16
WTP < t (No, No)	101
<i>Illegal seeds</i>	
WTP > 1600 (Yes, Yes)	101
t < WTP < 1600 (Yes, No)	23
800 < WTP < t (No, Yes)	6
WTP < 800 (Yes, Yes)	27

Source: Computations based on data from our survey.

where the I 's are indicator variables for each of the responses.

Following the exercise for legal seeds, specify the willingness to pay (for illegal seeds) by the j th grower as $Z_j = \gamma X_j + \eta_j$. Here we have four possible response sequences: (Yes, Yes); (Yes, No); (No, Yes); and (No, No). The likelihood of each of these responses can be written as:

- (i) $\Pr ob(Yes, Yes) = \Pr ob(Z_j > 1600) = \Pr ob(\gamma x_j + \eta_j > 1600) = \Pr ob(\eta_j > 1600 - \gamma x_j) = 1 - \Phi(1600 - \gamma x_j/\sigma)$
- (ii) $\Pr ob(Yes, No) = \Pr ob(t_j < Z_j < 1600) = F(1600) - F(t_j) = \Phi(1600 - \gamma x_j/\sigma) - \Phi(t_j - \gamma x_j/\sigma)$ and
- (iii) $\Pr ob(No, Yes) = \Pr ob(800 < Z_j < t_j) = \Phi(t_j - \gamma x_j/\sigma) - \Phi(800 - \gamma x_j/\sigma)$ and
- (iv) $\Pr ob(No, No) = \Pr ob(Z_j < 800) = \Phi(800 - \gamma x_j/\sigma)$

Table 6 summarizes the responses from both contingent valuation exercises. In the case of legal seeds, there are a large number of (No, No) responses suggesting that there should have been bid prices lower than the minimum of Rs. 1000. In the case of illegal seeds, there is the opposite problem as there are a large number of (Yes, Yes) responses. From Table 6, it is clear that the average willingness to pay is likely to be substantially greater for illegal seeds.

8. FARMER’S VALUATIONS OF BT SEEDS: ESTIMATES AND CORRELATES

Table 7 presents the descriptive statistics of the variables that are used as correlates of the willingness to pay. Farm size is a proxy for wealth. Land quality is measured by the proportion of cotton area that is irrigated as well as the proportion of cotton area that is of “good” soil quality. The wealth and land quality variables would be expected to increase a grower’s willingness to pay for Bt seeds. Farmer characteristics include age, education, and experience. It is not clear *a priori* how these would be correlated with willingness to pay. If Bt seeds are seen as an expensive and risky investment, then a grower’s valuation would be negatively correlated with age and positively with education and experience.

As Bt seeds (legal and illegal) are much more expensive than conventional hybrid seeds, a farmer incurs higher upfront costs and, therefore, the willingness to pay for them might be expected to be positively correlated with his access to credit. To proxy this, we construct a dummy for growers who have received a crop loan. Another variable that also proxies the credit constraint is the area under cotton for that grower. As

Table 7. Descriptive statistics of the correlates of willingness to pay

Variables	Mean	Standard deviation
Farm Size (Acres)	16.36	14.91
Farm Size squared (Acres squared)	488.55	1020.28
Proportion of cotton area irrigated	0.75	0.41
Proportion of cotton area that is of “good” soil quality	0.55	0.49
Age of Farmer (years)	46.99	11.79
Dummy if education ≥ 9 years	0.59	0.49
Dummy if grower took a crop loan	0.46	0.50
Cotton area (Acres)	7.87	8.16
Cotton area squared (Acres)	128.12	341.16
Dummy for whether Navbharat grower	0.64	0.48
Dummy for whether “desi” grower	0.182	0.387
Whether planted Bt in the past	0.37	0.48
Dummy for whether grower sprayed pesticides	0.86	0.35
Dummy if pesticides were applied by family member	0.55	0.50
Dummy if growers believe that insecticides have an impact on the environment	0.66	0.47
Dummy if growers believe that insecticides have an impact of health of workers who apply it	0.46	0.50

Source: Computations based on data from our survey.

Table 8. *Willingness to pay for legal seeds*

Variables	Coefficients β/σ	Robust <i>t</i> -stats	β
Farm size	0.11	2.52	78.80
Farm size squared	0.00	-2.50	-1.51
Proportion of cotton area irrigated	1.29	3.37	888.43
Proportion of cotton area that is of "good" soil quality	0.52	1.93	358.82
Age of farmer	-0.01	-1.25	-10.01
Dummy if education ≥ 9 years	-0.55	-2.23	-376.80
Dummy if grower took a crop loan	0.28	1.11	196.59
Cotton area	-0.09	-1.82	-63.24
Cotton area squared	0.00	2.20	1.84
Dummy for whether Navbharat grower	-1.03	-3.41	-711.05
Dummy for whether planted Bt in the past	0.60	2.41	414.21
Dummy for whether grower sprayed pesticides	-0.33	-0.66	-231.08
Dummy if pesticides were applied by family member	0.78	2.79	537.84
Dummy if growers believe that insecticides have an impact on the environment	0.72	2.32	497.29
Dummy if growers believe that insecticides have an impact of health of workers who apply it	0.23	0.80	158.86
Constant	0.03	0.03	20.14
($1/\sigma$)	0.00145	2.63	—
# of Observations	155		
Log-likelihood	-94.11		
Mean willingness to pay	Rs. 778		
Median willingness to pay	Rs. 880		

Source: Computations based on data from our survey.

area increases, other things remaining equal, it calls for greater upfront investment by growers in terms of seeds and other costs. If the grower is credit constrained, he typically opts for extensive cultivation and lowers the expenditure on inputs per acre of land. Thus, we would expect the crop loan dummy to be positively correlated and the cotton area to be negatively correlated with willingness to pay.

The Bt technology is expected to reduce pesticide use. If so, growers might value this technology depending on whether they used pesticides and whether they hired somebody to spray it or did it themselves. The discomfort with these actions would in turn depend on their beliefs about the impacts of pesticide use on the environment and on the health of workers who handle it. Responses from these questions are used as correlates of willingness to pay.

The impact of these correlates on the willingness to pay for legal seeds is summarized in Table 8. The willingness to pay (WTP) for legal seeds increases with farm size although at a decreasing rate. Irrigation and good soil quality also increase the WTP for legal seeds. Farmers perceive the Bt hybrids as water sensitive and as these seeds are expensive (relative to non-Bt seeds), they prefer not to use them on unirrigated lands. Education has a surprisingly negative effect on the valuation of legal seeds. The access to credit variables have the expected sign but statistical significance is clear only for the cotton area variable. Although experience in cultivating cotton turned out to be insignificant (and not included in the likelihood estimation reported here), experience with Bt cotton (whether planted Bt in the past) contributes positively to

Table 9. *Willingness to pay for F1 illegal seeds*

Variables	Coefficients γ/σ	Robust <i>t</i> -stats	γ
Farm Size	0.03	1.81	47.31
Proportion of cotton area irrigated	0.60	2.06	1043.68
Proportion of cotton area that is of "good" soil quality	0.31	1.29	532.41
Age of Farmer	-0.01	-0.95	-14.79
Dummy if grower took a crop loan	0.40	1.67	694.95
Cotton area	-0.03	-1.48	-59.36
Dummy for whether grower of "desi" variety	-0.78	-1.75	-1349.22
Dummy for whether grower sprayed pesticides	-0.73	-1.55	-1274.07
Dummy if pesticides were applied by family member	0.33	1.29	582.23
Dummy if growers believe that insecticides have an impact on the environment	0.80	2.72	1394.03
Dummy if growers believe that insecticides have an impact of health of workers who apply it	0.54	2.03	945.94
Constant	0.96	1.37	1669.21
($1/\sigma$)	0.00058	1.91	—
# of observations	154		
Log-likelihood	-122.8		
Mean willingness to pay	Rs. 3050		
Median willingness to pay	Rs. 3028		

Source: Computations based on data from our survey.

WTP. On the other hand, experience with Navbharat Bt dampens valuations.

Farmers have a higher valuation of legal Bt if a family member applies insecticides or if they believe that pesticides impact the environment (such as reducing the number of beneficial insects or through land degradation). Controlling for these variables, the dummy for whether a farmer believes pesticides have an impact on health is not significant. The last column of Table 8 reports the betas, that is, the marginal impact of the correlates on the willingness to pay. The variables that have a large positive impact are irrigation, experience with Bt, access to credit, the pesticide use variables, and the subjective perceptions of their impact. The variables that have a sizeable negative impact are education and the experience of the grower using Navbharat seeds.

The coefficient estimates can be used to compute and predict the expected willingness to pay of each individual in the sample. For the sample, the mean value of this variable is Rs. 778 and the median is Rs. 880. These estimates imply that legal seeds are overpriced and, therefore, have not been adopted widely.²⁵

Table 9 reports the estimates of the WTP function for illegal F1 seed (Navbharat 151 and its variants). Many of the variables significant in the WTP equation for legal seeds are insignificant here.²⁶ The wealth variable (farm size) is not significant at the 5% level and the coefficient associated with it has a relatively negligible impact on WTP (see last column of Table 9). Irrigation has a strong positive and significant impact. The marginal impact is bigger than what we observe in the case of WTP for legal seeds. Good soil quality has also a positive but not statistically significant impact. A variable that is significant here is whether the grower sprays pesticides. This was insignificant in the WTP for legal seeds. This variable has a negative sign indicating those who do not spray pesticides have a substantially higher valuation of illegal seeds. Like in the case of legal seeds, willingness to pay is higher for growers who sprayed pesticides themselves or with the help of family members and growers who believed that pesticides have an adverse impact on the environment and health. Thus, like in the case of legal seeds, a large chunk of the valuation of Bt seeds comes from the fact that growers value the reduction in pesticide use.

The mean WTP for illegal F1 seeds is as high as Rs. 3050. This is because of the large number of growers who report they are willing to pay at least Rs. 1600. As Rs. 1600 is the price at which legal seeds are sold, there could be an anchoring bias as growers could have perceived the question as eliciting a comparison between the illegal F1 seed and the MM seed. We also estimated the WTP function based on the first response alone. In this case, the likelihood function, on the assumption of normal distribution for disturbances, reduces to a probit model. The signs and magnitudes of the individual coefficients are in line with the earlier estimates. However, the mean WTP based on this model is much lower at Rs. 1975 which, however, is still substantially higher than the average WTP for illegal seeds.

9. CONCLUSIONS

Illegal Bt cotton varieties have diffused widely in the Indian state of Gujarat and, according to media reports, have spilled across the state boundaries as well. Their unchecked spread has been attributed to the near impossible task of monitoring and enforcing the law when potential violators involve millions of small farmers. Some critics of biotechnology have this

seen as a proof of weak regulatory capacity and as a reason enough for India not to permit the cultivation of genetically modified crops.

In this paper, we have argued that the absence of enforcement of biosafety laws does not indicate the lack of means on the part of government. As the production and distribution of illegal seeds is coordinated by a network of seed companies, seed producers, and seed dealers, enforcement is not difficult. The chain from seed plots to seed sales can be disrupted at any point. The lack of enforcement is an act of choice by the state governments.

The federal structure of government means that while biosafety approvals and laws are in the domain of the Central government, the task of enforcing the laws lies with the state government. As this paper shows, illegal seeds in the early to middle part of this decade performed just as well as legal seeds, if not better. Farmers valued them highly and their valuations were strongly correlated with their aversion to pesticides. Enforcing the law would have been unpopular with cotton growers. Why should the state government court such unpopularity?

Furthermore, the Bt gene contained in the illegal varieties (cry 1 Ac) is the same as that in the legal Mahyco-Monsanto Bt hybrids. The cry 1 Ac gene has been extensively tested in India and abroad for biosafety. For new approvals of Bt hybrids carrying this gene, Indian regulators do not require biosafety tests. The state government, unconstrained by fears of environmental consequences, has made a choice, it would appear, according to straightforward political calculus.²⁷ The mobilization of farmers around economic issues is not so straightforward, however; possibly what tilted the political economy in Gujarat was the constituency of seed producers and local seed companies that exists because of the position of the state as a major hybrid seed producer.²⁸ It is interesting to note that illegal seeds have not diffused widely in the neighboring cotton growing state of Maharashtra. Hybrid seeds are not produced in this state; moreover the state is the home of Mahyco Monsanto Biotech.

The pressures to enforce biosafety and IPR type regulations may possibly be stronger in future years. Since 2005 there have been some changes to strengthen the structure for enforcing biosafety regulations at the state and district levels. State and district level biosafety committees have been formed throughout India. Firms are also starting to apply for plant variety protection. In addition, new seed laws require that all new varieties be registered and no longer allows the sale of unregistered but "truthfully labeled" seed. To register their varieties, companies will have to show the ancestors of their varieties and that the varieties themselves are distinct from other varieties that are already on the market. This could cut down on copying of varieties and simply putting another name on them. It will also put in place another means of tracking varieties protected by the plant variety protection act.

The Bt cotton episode illustrates a generic issue with IPRs. While governments would like to establish IPRs, "de jure" and "de facto," to attract private investment in agricultural R&D, they have little incentive to enforce them if the innovation is successful and promises large social gains with widespread adoption. Indeed, in the case of illegal Bt cotton seeds, which have proven in farmers' fields to be as effective as the legal varieties, it is clearly not optimal to enforce the law and deprive farmers of a well adapted variety in the short run. The federal structure of government where it is the task of the Central government to formulate biosafety and IPR policies and the responsibility of State governments to enforce them makes the time consistency problem of IPR type of pro-

tections more acute. The illegal Bt seeds phenomenon is not the only instance where a State government has sought to erode the monopoly of legal seeds. As mentioned earlier, in the 2006 season, the Andhra Pradesh government imposed price controls on legal Bt cotton seeds citing farmer complaints about their high price.²⁹

The reluctance of state governments to commit to IPR protections, which are not optimal ex-post, will, however, affect the incentives of biotech firms to develop products. The more successful the innovation and more widespread is its adoption, the greater will be the pressure on local governments to compromise the ability of private investors to appropriate gains from them. Kremer and Zwane (2005) advocate government buy-out of privately developed agricultural innovations that meet pre-specified criteria (for example, finger millet varieties that are resistance to blast—a fungal disease) where the re-

ward to technology innovators is proportional to the adoption of the product. In principle, such “pull” programs could resolve the tension in IPRs between ex-ante and ex-post optimality.

In the case of illegal Bt cotton seeds, a “pull” program would compensate the technology innovators in relation to the social gains from the diffusion of illegal seeds. At the same time, the government could permit the Navbharat Bt cotton seeds and its variants to be officially evaluated by biosafety regulators. Legalization would allow the regulator to monitor the expression of Bt trait without depriving growers of well adapted hybrids. The other social gain would be that the dissemination of the superior illegal seeds would no longer be limited by the word-of-mouth advertising and the informal social networks of the underground seed economy.

NOTES

1. There is an extensive literature debating the merits of strong IPRs (as opposed to public sector R&D or open source platforms) as a mechanism to spur innovation. Our concern here is a more limited point, if private firms have no way of capturing some of the economic benefit of investment (whether through IPRs or other means), they are unlikely to invest. In agriculture, this explains why private firms do not invest in varieties but do so in hybrids. Kremer and Zwane (2005) discuss the funding of agricultural research in situations when firms cannot appropriate enough of the gains from such research.
2. Venkateswarlu (2004).
3. Public policy in most countries presumes that the departure is significant enough to call for special regulation of transgenic plants not applicable to conventionally bred plants. The scientific literature is not so categorical, however. A review by a committee of the National Research Council in the United States concluded that “The transgenic process presents no new categories of risk compared to conventional methods of crop improvement, but specific traits introduced by either of the approaches can pose unique risks” (National Research Council, 2002).
4. India amended its Patent Act in 1999, 2002 and 2005 to comply with the Trade Related Aspects of Intellectual Property Rights (TRIPs) Agreement. The TRIPs agreement requires that patents be provided for micro-organisms. It is unclear, however, to what extent the Indian law is consistent with this provision. It is also not known how the Indian patent office will choose to define micro-organisms.
5. It has been told to us that a leading seed company was rebuffed by the regulatory authority when it tried to obtain legal approvals for its Bt hybrids with an unlicensed MMB gene.
6. This has been recognized by others as well. Herring (2007) points out “Monsanto would prefer the strict regulated capitalism promulgated by the state, in which the only legal seeds are its seeds. Market-rigging *via* biosafety rules is preferable for would-be monopolists.”
7. Pray *et al.* (2005) note that compliance costs have been significantly lower for transgenic plants produced by the public research system.
8. The interests of large firms in favoring strict regulation as a way to create barriers to entry are also recognized in Graff, Hochman, and Zilberman (2009). This paper examines the political economy processes that shape biotechnology regulations.
9. These papers typically abstract from general equilibrium effects. For effects on labor markets and on poor households, see Subramanian and Qaim (2009, 2010).
10. In this respect, the Indian experience is materially different from that in Brazil and China.
11. Shah states that growers are supplied with 240 gm of Bt male and 600 gm of the parent female (usually from GujCot 8 line) are supplied for one acre which produces anywhere between 100 and 300 kg of seed.
12. These would not be of much use to growers, however, unless they are breeders as well.
13. It should be noted that here we are going by farmer reported variety names. If a variety has different names in different regions, then the number of distinct varieties would be less than number of distinct names.
14. Note that corresponding sets of growers are not disjoint—for instance, a grower might grow a legal Bt variety as well as an illegal Bt hybrid.
15. The “desi” or traditional cotton varieties belong to *G. Arboreum* which are known for their drought tolerance and resistance to sucking pests.
16. A referee has found it remarkable that illegal Bt hybrids cost much more than legal non-Bt hybrids in the year of our survey. This is a reflection of the strong demand for Bt varieties. In our fieldwork, farmers reported that out of the three officially approved varieties, only one of them Mahyco 161 performed well. As a result, many farmers opted for the illegal varieties. The gap between the demand and the supply of illegal F1 Bt seed created space for the use of illegal F2 Bt seed.
17. Our survey did not anticipate the extent of F2 use and, therefore, it did not contain questions to probe why growers choose F2. Our impression is that the gap between the demand and supply of illegal F1 Bt seed led some growers to try F2 Bt seeds.
18. On the other hand, a competitive market would not recoup the costs of R&D and would therefore provide no incentives for it. This does not apply to the illegal seeds producers, however, as they have not incurred the costs of developing the Bt seed.

19. Fieldwork in subsequent years indicates that the entry of more legally approved hybrids have led prices of illegal seeds to come down.
20. In their study of pesticide use in Shandong province of China, Pems, Waibel, and Gutierrez (2005) similarly report that “farmers who pay more for their seed also spend more money on insecticides and other inputs.”
21. Even with data from multiple years, econometric analysis must cope with a variety of problems including selection bias and comparison of non-isogenic lines. For a review of these difficulties and the empirical evidence on the impact of GM crops in developing countries, see Smale, Zambrano, and Cartel (2006).
22. Stone does not suggest that fads drive seed choices everywhere and at all times. In particular, he acknowledges that Bt cotton in Gujarat might have greater grounding in farmer knowledge and learning.
23. For a previous application of contingent valuation methods to Bt cotton, see Qaim and de Janvry (2003). Our bid design is different from theirs.
24. A packet consists of 450 gm of seed.
25. It should be noted that during the time of study, the only legal seeds were the varieties from Mahyco Monsanto and this finding applies to them. In later years, other legal Bt varieties have become available which have diffused more successfully.
26. This happens because there is not enough variation in the dependent variable because of the large number of the (Yes, Yes) responses that was noted earlier.
27. There is a long-term concern, however, that if the expression of Bt toxin is weaker in some varieties of illegal seeds and particularly in the F₂s, then that could speed up the evolution of bollworms resistant to Bt. Regulators require that farmers plant refuge (of non-Bt cotton) to slow the development of Bt resistant strains. In our sample, a negligible fraction of growers plant refuge, irrespective of whether the Bt variety is legal or not.
28. Local seed companies and seed producers are well organized. We attended a meeting of such an organization where the representatives spoke of their ties to politicians. They acknowledged that did not prevent occasional attempts at enforcement in the form of raids and arrests. While they resented such attacks they also understood the dilemma of the state government which could not be seen to be openly backing enterprises outside the law. The major criticism was against the Central government for backing a foreign multinational against home grown enterprise.
29. A referee has pointed out that the price control on Bt cotton seeds may have led to greater adoption and thus higher market share and profits for the monopolist supplier. This is certainly possible if the initial price was set higher than the monopoly profit maximizing price, a possibility that was empirically established for Argentina by Qaim and de Janvry (2003).

REFERENCES

- Bambawale, O. M., Singh, A., Sharma, O. P., Bhosle, B. B., Lavekar, R. C., & Dhandapani, A. (2004). Performance of Bt cotton (MECH-162) under Integrated Pest Management in farmers' participatory field trial in Nanded district, Central India. *Current Science*, 86(12), 1628–1633.
- Bennett, R. M., Ismael, Y., Kambhamapati, U., & Morse, S. (2004). Economic impact of genetically modified cotton in India. *AgBioForum*, 7(3), 96–100.
- da Silveira, J. M. F. J., & de Carvalho Borges, I. (2007). Brazil: Confronting the challenges of global competition and protecting biodiversity. In S. Fukuda-Parr (Ed.), *The gene revolution* (pp. 104–129). London: Earthscan.
- Fukuda-Parr, S. (2007). Institutional changes in Argentina, Brazil, China, India and South Africa. In S. Fukuda-Parr (Ed.), *The gene revolution*. London: Earthscan.
- Graff, G. D., Hochman, G., & Zilberman, D. (2009). The political economy of agricultural biotechnology policies. *AgBioForum*, 12(1), 34–46, <<http://www.agbioforum.org>>.
- Herring, R. J. (2007). Stealth seeds: Biosafety, bioproperty, biopolitics. *Journal of Development Studies*, 43(1), 130–157.
- Huang, J., Hu, R., Rozell, S., & Pray, C. E. (2007). China: Emerging public sector model for GM crop development. In S. Fukuda-Parr (Ed.), *The gene revolution* (pp. 130–155). London: Earthscan.
- Kranthi, K. R., & Kranthi, N. R. (2004). Modelling adaptability of cotton bollworm, *Helicoverpa amiger*a to Bt-cotton in India. *Current Science*, 87(8), 1096–1107.
- Kremer, M., & Zwane, A. P. (2005). Encouraging private sector research for tropical agriculture. *World Development*, 33(1), 87–105.
- Lalitha, N., Ramaswami, B., & Viswanathan, P. K. (2009). India's experience with Bt cotton: Case studies from Gujarat and Maharashtra. In R. Tripp (Ed.), *Biotechnology and agricultural development: Transgenic cotton, rural institutions and resource-poor farmers*. London: Routledge.
- Murugkar, M., Ramaswami, B., & Shelar, M. (2007). Competition and monopoly in the Indian cotton seed market. *Economic and Political Weekly*, 62(37), 3781–3789.
- Naik, G., Qaim, M., Subramanian, A., & Zilberman, D. (2005). Bt cotton controversy: Some paradoxes explained. *Economic and Political Weekly*, 40(15), 1514–1517.
- National Research Council. (2002). Environmental effects of transgenic plants: The scope and adequacy of regulation. Washington DC: National Academy Press.
- Nuffield Council on Bioethics. (2004). The use of genetically modified crops in developing countries. Nuffield Council: London.
- Pems, D., Waibel, H., & Gutierrez, A. P. (2005). Why do some Bt-cotton farmers in China continue to high levels of pesticides?. *International Journal of Agricultural Sustainability*, 3(1), 44–56.
- Pray, C., Bengali, P., & Ramaswami, B. (2005). The cost of biosafety regulation: The Indian experience. *Quarterly Journal of Agriculture*, 44(3), 267–289.
- Qaim, M. (2003). Bt cotton in India: Field trial results and economic projection. *World Development*, 31(12), 2115–2126.
- Qaim, M., & de Janvry, A. (2003). Genetically modified crops, corporate pricing strategies, and farmers' adoption: The case of Bt cotton in Argentina. *American Journal of Agricultural Economics*, 85(4), 814–828.
- Ramaswami, B., & Pray, C. (2007). India: Confronting the challenge—the potential of genetically modified crops for the poor. In S. Fukuda-Parr (Ed.), *The gene revolution* (pp. 156–174). London: Earthscan.
- Roy, D., Herring, R. J., & Geisler, C. C. (2007). Naturalising transgenics: Official seeds, loose seeds and risk in the decision matrix of Gujarati cotton farmers. *Journal of Development Studies*, 43(1), 158–176.
- Sahai, S. (2005). Is agricultural biotechnology suited to agricultural production in India. In R. Chand (Ed.), *India's agricultural challenges* (pp. 161–170). Delhi: Centre for Trade and Development.
- Shah, E. (2005). Local and global elite join hands: Development and diffusion of genetically modified Bt cotton technology in Gujarat. *Economic and Political Weekly XL*, (43), 4629–4640.
- Smale, M., Zambrano, P., & Cartel, M. (2006). Bales and balance: A review of the methods used to assess the economic impact of Bt cotton on farmers in developing economies. *AgBioForum*, 9(3), 195–212.
- Stone, G. D. (2007). Agricultural deskilling and the spread of genetically modified cotton in Warangal. *Current Anthropology*, 48(1), 67–87.

- Subramanian, A., & Qaim, M. (2009). Village-wide effects of agricultural biotechnology: The case of Bt cotton in India. *World Development*, 37(1), 256–267.
- Subramanian, A., & Qaim, M. (2010). The impact of Bt cotton on poor households in rural India. *Journal of Development Studies*, 46(2), 295–311.
- Venkateswarlu, D. (2003). Child labour and trans-national seed companies in hybrid cottonseed production in Andhra Pradesh, India Committee of Netherlands, The Netherlands. <<http://www.india-net.nl/cotseed.html>>.
- Venkateswarlu, D. (2004). Child labour in hybrid cotton seed production in Gujarat and Karnataka. <<http://www.germanwatch.org/tw/baystug.pdf>>.

Available online at www.sciencedirect.com

SciVerse ScienceDirect