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THE LIMITS OF INTELLECTUAL PROPERTY RIGHTS:

Lessons from the spread of Illegal Transgenic Cotton Seeds in India

Bharat Ramaswami
Carl. E. Pray
N. Lalitha

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Gota, Ahmedabad 380 060

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Abstract

Genetically modified seeds have to be approved by biosafety regulators before they are commercialized. Unapproved seeds are, however, common in many developing countries including Brazil, China and India. Their unchecked spread has been attributed to the difficulties of monitoring and enforcing the law when potential violators involve millions of small farmers. Unapproved seeds could potentially pose dangers to biosafety and also undermine the intellectual property rights of firms that own the genetically modified trait. Based on a survey of cotton growers in Gujarat in 2004, the paper addresses three questions. Is the lack of enforcement because of obstacles stemming from smallholder agriculture involving large number of growers? Our analysis of government institutions and the nature of hybrid seed production suggest that regulations could have been enforced. If this is so, why was unapproved seed allowed? And thirdly, where does socially optimal policy lie? Does it lie in strict enforcement? If not, how can India provide for biosafety and structure incentives for the development and commercial release of new technologies?

JEL Classification : K42, O34, Q16
Keywords : Intellectual Property Rights, Biosafety Regulation, Genetically Modified Seeds, Transgenic Varieties, Bt Cotton

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Bharat Ramaswami*
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N. Lalitha***

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 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. This is a complex task especially for developing countries. The setting of risk protocols and procedures requires a careful balance between the needs for biosafety and the need for early dissemination of useful technology[1].

Biosafety regulations can also have unintended consequences. Between 2002 and 2006, 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 the major pest, the bollworm. The regulations in effect gave MMB a monopoly on the sale of legal Bt.

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

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* Bharat Ramaswami (bharat@isid.ac.in) is Professor at the Indian Statistical Institute, New Delhi.

** Karl E. Pray (pray@aesop.rutgers.edu) is Professor at Cook College, The State University of New Jersey, USA.

*** N. Lalitha (lalitha@gidr.ac.in; lalithanarayanan@gmail.com) is Associate Professor at GIDR, Ahmedabad.

[1]For an analysis of how this trade-off worked out in the Indian context, see Pray, Bengali and Ramaswami, (2005).

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 unapproved seeds, but they decide not to do so? Then the question becomes why doesn't the government enforce these laws? Why do they give up on biosafety? In the Indian case, the biosafety implications are possibly not that compelling because the unapproved seeds are simply `underground' versions of approved seeds carrying the gene and trait.

However, unapproved seeds clearly undermine the intellectual property rights of the firms that own the genetically modified trait. The firm responsible for the innovation would receive little or no benefit from the diffusion of the unapproved seeds. By contrast, the price of approved seeds includes a technology fee payable to the owner of the genetically modified trait. The enforcement of biosafety regulations contains the essential dilemma of intellectual property rights – 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 unapproved seeds, then companies might decide not to make available newer seeds as they become available in the future.

This paper examines these difficulties of regulation in the context of spread of unapproved transgenic Bt cotton seeds in India. Based on a survey of cotton growers in Gujarat in 2004, the paper addresses three questions. The first question is whether the lack of enforcement is because of obstacles stemming from smallholder agriculture and the large number of growers? Our analysis of government institutions and the nature of hybrid seed production suggest that regulations could have been enforced. If this is so, why was unapproved seed allowed? And thirdly, where does socially optimal policy lie? Does it lie in strict enforcement? If not, how can India provide for biosafety and structure incentives for the development and commercial release of new technologies? Further, this paper also examines the impact of the cultivation of approved and unapproved seeds on farmers and also examines the farmers' valuation of Bt seeds.

These are analysed in the different sections of the paper. Section 2 presents the scenario of cotton hybrids and Bt cotton in India. Sections 3 and 4 present the institutional structure of Indian biosafety regulations and the intellectual property rights for agricultural innovations. Section 5 and the subsections analyse the diffusion of unapproved seeds and the economics of cultivation of approved and unapproved seeds. Section 6 presents the farmer's valuation of Bt seeds in terms of their willingness to pay using the contingent valuation method and Section 7 presents the conclusions.

2. Cotton hybrids and Bt Cotton

Although India grows all the cotton species – old world cottons (*G. Arboreum and G. Herbaceum*) and new world cottons (*G. Hirsutum* and *G. Barbadense*), the principal species are cultivated are *G. Arboreum* and *G. Hirsutum*. The `desi' or traditional cotton varieties belong to *G. Arboreum* which are known for their drought tolerance and resistance to sucking pests. On the other hand, new world cottons have long and extra long staple and better spinning potential (higher counts) than desi cottons.

Most cotton in India is now cultivated in the form of *G.Hirsutum* hybrids. Overall, these hybrids account for 70 per cent of all India plantings (Murugkar, *et al.*, 2007). Crosses are possible between varieties of the same species. Crosses across species are restricted to be either within the category of new world cottons or to be within old world cottons. Intra-*hirsutum* crosses dominate the hybrid cotton seed market in India. Maharashtra, Andhra Pradesh and Gujarat are the leading cotton growing states in India.

The first cotton hybrid H4 was developed by the Gujarat Agricultural University[2]. H4 and its variants have held sway in Gujarat for a long time. Among private bred hybrids in Gujarat, those from Vikram Seeds have been market leaders till recently (Murugkar, *et al.*, 2007). The private sector does not invest resources in breeding varieties as farmers can save and use seed for them for several generations. With hybrid seed, however, second generation (F2) seeds are a genetic mixture (which increases with successive generations) and their yields are significantly lower than the first generation (F1) seeds.

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 labour intensive and requires about 10 times

[2] India was the first country to commercialize cotton hybrids.

more labour than cotton production (Venkateswarulu, 2003). An alternative and much less labour 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 cottonseed production in the country out of which 26,000 were in Gujarat and 14,000 acres in Andhra Pradesh (Venkateswarlu, 2004).

Bt cotton is a radical departure from conventional plant breeding. *Bacillus thuringiensis* (Bt) is a soil borne bacterium toxic to 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 genetic 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 and 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.

3. The Institutional Structure of Indian Biosafety Regulation

Indian regulatory institutions have three layers. At the bottom, an institutional bio-safety committee (IBC) must be established in any institute using DNA in its research. These committees comprise institute scientists and also a member from the Department of Biotechnology within the Central government. The IBC can approve research done at the institute unless it involves a particularly hazardous gene or technique. That type of research must be approved by the Review Committee on Genetic Manipulation (RCGM), the next layer of the system.

The RCGM, within the DBT, regulates agricultural biotech research up to large-scale field trials. It requests food bio-safety, environmental impact and agronomic data from applicants wishing to do research or conduct field trials and gives permits to import transgenic material for research. It consists primarily of scientists, including agricultural scientists, and can request specialists to review cases. Its Monitoring-cum-Evaluation Committee monitors field trials of transgenic crops.

The Genetic Engineering Approval Committee (GEAC), under the Ministry of Environment and Forests, is the agency that gives permits for commercial production, large-scale field trials and imports of transgenic products. Although scientists are members of this committee, bureaucrats representing different ministries predominate. Besides food and environment safety, the GEAC also requires evidence of agronomic performance and that the variety in question is economically beneficial for farmers. If an approved transgenic event is backcrossed into a new plant variety, the developers of the new variety do not have to produce new food safety and environmental data. However, they do have to put it through agronomic trials which can take up to two years.

4. Intellectual Property Rights for Agricultural Innovations

In India, a formal legal framework for the protection of agricultural innovations is in its infancy. The Plant Variety Protection and Farmer's Rights Act was passed in 2001. This Act provides for plant breeder's rights, which requires extant and new plant varieties to be registered on the basis of characteristics relating to novelty, distinctiveness, uniformity and stability. While the law is on the books, the office accepting applications was not operational until 2007. The private seed industry is starting to file applications for protection of hybrids and inbred lines, but it may not be used extensively because the rights as they exist are so weak as to provide few incentives for innovation (Srinivasan, 2004).

The other major change in intellectual property protection has been the change in patent laws. The Trade Related Aspects of Intellectual Property Rights (TRIPs) Agreement came into force in WTO member countries in 1995. This requires member countries to comply with stipulated minimum standards for intellectual property rights protection. As a result, India amended its Patent Act in 1999, 2002 and 2005. The major impact of these provisions has been to provide product patents in the area of pharmaceuticals. However, the changes have implications for biotechnology innovations as well. 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. Six patent applications related to cotton have been filed in India till December 2003 (Ramanna, 2005). None have been granted yet. In their survey of the cotton seed industry, Murugkar *et.al* (2007) conclude that patenting was not an important element of the current business environment. Despite this, however, transnational companies have sought to commercialize agricultural biotechnology products in India. Why? How could they secure their investments without patents?

4.1 `De facto' IPRs and Market Structure

The first genetic event to be approved was the insertion of a Bt gene (*cry*1Ac), 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 and 2005, 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 been patented in India. 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 unapproved 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[3]. Thus, the biosafety regulation creates `de facto' intellectual property rights for the legal Bt cotton[4].

Biosafety regulatory processes also constitute an entry barrier for new genes. Pray *et. al* (2005) report the compliance costs of early products such as MMB's first *Bt* cotton hybrids and Bayer's GM mustard hybrid that went through the regulatory system. In the case of MMB, pre-approval costs were about US$1.8 million, of which $300,000 was spent on field trials.

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.

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[3] 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.

[4] 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 approved seeds are its seeds. Market-rigging *via* biosafety rules is preferable for would-be monopolitists.”

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[5].

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 seed 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 seed (relative to non-hybrids and relative to Bt cotton seed 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 seed costs, most research papers have found that growers have gained substantially by growing Bt cotton (Bambawale *et.al,* 2004; Bennet *et.al* 2004; Naik *et.al,* 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. 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

[5] Pray *et. al* (2005) note that compliance costs have been significantly lower for transgenic plants produced by the public research system.

growers and also greater diffusion, it would also mean that MMB receives no rewards for its technology, severely jeopardising incentives for future product development from MMB and other potential technology suppliers.

5. The Diffusion of Unapproved 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 unapproved 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.

Navbharat Seeds has been barred from the cotton seed business and has been prosecuted for violating the biosafety laws (under environmental protection laws). Yet despite this, the multiplication and distribution of the unapproved seed continued to spread. As can be seen in Table 1, unapproved seed plantings have diffused rapidly and covered an area larger than under approved seed until 2006. However, unapproved seeds are geographically concentrated in Gujarat and can be found to a lesser extent in Punjab and Andhra Pradesh.

Table 1: Diffusion of Bt Cotton (million acres)

Details	2002-03	2003-04	2004-05	2005-06	2006-07 (P)	2007-08 (F)
Area Under Approved Bt Hybrids	28	90	500	1300	3800	4800
Area Under Unapproved Bt Cotton	30	120	600	1200	2000	1800
Total	58	210	1100	2500	5800	6600

Notes: (P) – Provisional; (F) – Forecast.

Source: Santosh Singh India Cotton and Products Annual 2007. USDA Foreign Agricultural Service GAIN Report Number: IN7041 5/15/2007

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 approved seed. Herring's characterization of the proliferation of unapproved 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 unapproved 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 unapproved Bt cotton seeds are hybrids[6]. 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 unapproved F1 seeds. Where do farmers get these from?

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 centre 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 labour and five times more capital) than normal cotton cultivation and growers hire labour (often children and young women) for cotton seed production (Venkateswarlu, 2003).

[6] In this respect, the Indian experience is materially different from that in Brazil and China.

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 unapproved seeds. Our interviews with farmers indicate that they obtained the seeds from "other growers" or seed dealers. The "other growers" that supplied the seed were not the producers of the seeds but were sales agents of the producers. Our fieldwork suggests that unapproved Bt cotton seed production and sales is 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 unapproved 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 unapproved seed sales happen through two channels. The traditional channel is through companies which produce hybrid seed through contract production[7]. But Shah also finds that seed multiplication and sales also occurs through farmers and that parent Bt male seeds were available in the market[8]. However, even here Shah cites the importance of access to skilled labour (seasonal migrant labour in this case) for seed production. Shah also finds that unapproved 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 which 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 unapproved seeds rested not so much on

[7] Shah states that growers are supplied with 240 grams of Bt male and 600 grams of the parent female (usually from GujCot 8 line) are supplied for one acre which produces anywhere between 100 to 300 kgs of seed.

[8] These would not be of much use to growers, however, unless they are breeders as well.

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 unapproved seeds could not be curbed by penal action against millions of growers. However, seed produces 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, unapproved seed sales try to soften their challenge to the law by taking care to mask the seed sales as seed exchange. The unapproved 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 unapproved seeds? Our hypothesis is that the unapproved seed is highly profitable to farmers, that they see environmental and health benefits rather than problems from the unapproved seed, and as a result state governments have strong political incentives to do nothing.

5.1. Impact of unapproved and approved Bt cotton on farmers

None of the published studies on Bt cotton have separated the impact of approved and unapproved Bt cotton on farmers. So we set out to collect this type of data in 2004. Our data comes from a stratified survey of 160 randomly picked cotton growers in the districts of Rajkot, Bhavnagar, Bharuch and Vadodara. In each district, 4 talukas were chosen randomly and within each taluka 2 villages were chosen randomly. In each village, a listing of cotton growers was made out of which 5 growers were picked randomly. The survey was conducted during April-May of 2004 and the information collected pertained to the Kharif season of 2003/04 which in some cases ended as late as March 2004.

Nearly three quarters of the sample farmers grow Bt. Most of these Bt growers (82%) do not grow any other type of cotton. As many as 57 per cent of the Bt growers planted Bt for the first time in the 2003-04 season. As for the non-Bt users, about 20 per cent 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, unapproved Bt dominates Bt plantings. About 71 per cent of Bt growers grow unapproved Bt only; 13 per cent grow the approved MMB Bt varieties only; while the remainder 16 per cent use both types. Almost 85 per cent of cotton farmers spray pesticide. Most of the pesticide application is done manually using family labour.

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.

5.2 Comparisons by variety

We have area, yield and seed price information for each cotton variety 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[9]. The distribution of area under the principal cultivars is in Table 2. As noted earlier, unapproved 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.

Table 2: Distribution of Principal Cotton Varieties

Variety Name	Category	Proportion of area
1. Sanju hybrid	Non-Bt Hybrid	1.41
2. Shankar 6	Non-Bt Hybrid	2.32
3. Shankar 8	Non-Bt Hybrid	5.95
4. Desi Gujarat 23	Desi	5.71
5. Desi	Desi	18.76
6. Sarthi	Unapproved Bt hybrid	1.20
7. Unknown Bt	Unapproved Bt hybrid	2.96
8. Rakshak	Unapproved Bt hybrid	3.44
9. NB 151	Unapproved Bt hybrid	9.49
10. NB 151 - F2	Unapproved Bt hybrid	20.34
11. Mahyco 162	Legal Bt hybrid	2.43
12. Mahyco 12	Legal Bt hybrid	7.35
All of the above		81.36

Source: GIDR Farm Survey (2004).

[9] 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.

In our sample, 55 per cent of the cotton area is planted with Bt varieties – unapproved seeds are predominant, accounting for 43 per cent of area (Table 3). While Bt cotton plots tend to be smaller than non-Bt plots, the proportion of area that is irrigated is significantly higher. However, there is no significant difference in soil quality. Table 3 also shows that approved 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 unapproved 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 unapproved seeds.

Table 3: Group Comparisons: Land and Seed Source

Details of cotton area and seed sources	Non-Bt	Approved Bt	Unapproved Bt
1. As % of all cotton area	45	12	43
2. Size of cotton plot (acres)	7.85	4.45	5.25
3. Proportion of Area Irrigated (ratio)	0.67	0.93	0.82
4. Proportion of area that is good soil quality (ratio)	0.55	0.66	0.50
5. Medium soil quality	0.40	0.34	0.47
6. Bad Soil quality	0.05	0.00	0.03
7. Proportion of area that has seed sourced from seed dealer	0.42	0.82	0.17
8. Proportion of area that has seed sourced from State Seed Corporation	0.19	0.01	0.03
9. Proportion of area that has seed sourced from other farmers	0.14	0.11	0.56
10. Proportion of area cultivated with farm saved seed	0.07	0.00	0.01
11. Proportion of area that has seed sourced from other sources	0.15	0.06	0.23

Source: GIDR Farm Survey, 2004

Table 4 compares household size, its composition, age profile and education across growers of non-Bt seeds, legal Bt seeds and unapproved Bt seeds[10]. It demonstrates that there are no significant differences in terms of household demographic characteristics between the growers of different kinds of cotton varieties.

[10] Note that corresponding sets of growers are not disjoint – for instance, a grower might grow a approved Bt variety as well as an unapproved Bt hybrid.

Table 4: Grower Comparisons: Household Demographics

Household demographics	Non-Bt	Legal Bt	Unapproved Bt
1. Household Size – Overall (No)	5.29	5.79	5.25
2. No. of Male adults	1.90	2.00	2.04
3. No. of Female adults	1.66	1.65	1.67
4. Male adults with <= 3 yrs of education (proportion)	0.04	0.03	0.05
5. Male adults with > 3 yrs and <= 8 yrs of education (proportion)	0.26	0.27	0.26
6. Male adults with > 8 yrs and <= 12 yrs of education (proportion)	0.45	0.50	0.42
7. Male adults with > 12 yrs of education (proportion)	0.25	0.20	0.27
8. Female adults with <= 3 yrs of education (proportion)	0.07	0.05	0.08
9. Female adults with > 3 yrs and <= 8 yrs of education (proportion)	0.38	0.41	0.34
10. Female adults with > 8 yrs and <= 12 yrs of education (proportion)	0.27	0.24	0.26
11. Female adults with > 12 yrs of education (proportion)	0.29	0.31	0.32
12. Age of Farmer (years)	45.43	45.88	47.70
13. Education of Farmer (years)	10.31	8.76	10.18

Source: GIDR Farm Survey, 2004

Table 5 compares input use and yields across a five fold classification of cotton varieties – *desi* varieties, non-Bt hybrids, approved Bt hybrids, unapproved Bt hybrids (excluding, however, F2 seeds) and unapproved Bt F2 seeds. As expected, seed costs are highest for approved Bt seeds and lowest for *desi* varieties.

Table 5: Plot Comparisons: Input Use, Yield and Price

Items for comparison	Plots planted with				
	Desi	Non-Bt hybrid	Approved Bt	Unapproved F1 Bt	Unapproved F2 Bt
1. Seed cost: Rupees/acre	42	317	1346	916	124
2. No. of pesticide sprays against bollworms	0.64	5.34	4.18	3.24	2.72
3. No. of pesticide sprays against sucking pests	0.54	5.05	5.21	5.51	4.89
4. No. of pesticide sprays against other pests	0.18	2.16	1.76	2.29	1.32
5. Total Number of pesticide sprays	1.36	12.55	11.15	11.04	8.94
6. Fertiliser cost: Rupees/acre	93	2835	4764	2640	1645
7. Yield (kgs/acre)	199	653	999	1148	734

Source: GIDR Farm Survey, 2004

The unapproved Bt seed (excluding F2 seeds) costs as much as 68 per cent of the approved Bt seed. Contrary to what is generally conjectured, the unapproved F1 Bt seed is not much cheaper than the approved Bt seed. It is the unapproved Bt F2 seeds which are inexpensive and much cheaper than the non-Bt hybrid seed.

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)[11]. While MMB was the only supplier of approved Bt seeds in 2004, the situation as we described in an earlier section, was decidedly murky for unapproved 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, Herring and Geisler (2007) commented "In Gujarat, something like the obverse of monopoly is evident in the fields – a rare competitive market". Yet, as Table 5 shows, the unapproved Bt seeds in 2004 still cost more than three times as much as non-Bt hybrids.

This strongly suggests that the market for unapproved Bt seeds was anything but competitive. It could be either 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 unapproved Bt possessed market power[12]. This also confirms that the diffusion of unapproved Bt cannot just be due to farmer reproduction and exchange.

Approved Bt cotton growers seem to practice more intensive agriculture than the other cotton growers[13]. They use more fertiliser and pesticides than either the unapproved Bt cotton growers or the non-Bt category. There is no significant difference between pesticide costs of unapproved and non-Bt cotton fields. Thus, pesticide savings which have been an important source of benefits from Bt cotton seem to be absent for Gujarat producers. When measured by number of sprays, however, growers spray fewer times against bollworms on Bt cotton fields (whether approved or unapproved) than on non-Bt cotton. Also, as expected, there is no difference between the groups with regard to sprays against other insects which confirms similar findings in Qaim (2003) and Bennett *et. al* (2004).

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[11] 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 unapproved seeds producers, however, as they have not incurred the costs of developing the Bt seed.

[12] Fieldwork in subsequent years indicate that the entry of more legally approved hybrids have led prices of unapproved seeds to come down.

[13] In their study of pesticide use in Shandong province of China, Pemsl, Waibel and Gutierrez (2005) similarly report that "farmers who pay more for their seed also spend more money on insecticides and other inputs"

Average yields of Bt cotton, whether approved or unapproved, whether F1 or F2, are significantly higher than yields of non-Bt hybrids. The yield advantage of approved Bt hybrids is about 50 per cent, while that of unapproved F1 Bt hybrids is over 70 per cent. Even the average yield of F2 Bt hybrids is higher than that of non-Bt hybrids by more than 10 per cent. These patterns in yield differences persist even after we controlled for differences in land quality, inputs and locations. We do not report these regressions.

The tables are revealing about the economics of the choice between non-Bt hybrids and unapproved F2 generation Bt seeds. The latter is higher yielding and needs less pesticide application than the former. In other words, illegal F2 Bt seeds dominate non-Bt hybrids in performance and cost. In other words, unapproved F2 Bt seeds dominate non-Bt hybrids in performance. Similarly, the economics of the choice between approved and unapproved 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 unapproved hybrids. The popularity of unapproved 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.

6. 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. In a context 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 therefore it is 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[14]. 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.

[14] 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.

To do this, we undertook parallel contingent valuation exercises for both approved and unapproved seeds[15]. For the approved 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 consisting of 450 grams of seed. 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 3 possible responses: Yes, No; Yes and No; No. Nearly 26 per cent 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 approved seed sold at Rs. 1600 per packet, this price is likely to be fixed in the minds of respondents 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 elicited farmer's willingness to pay for unapproved 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 unapproved seed where *X* was randomly varying between Rs. 900 and Rs. 1500 (the randomization was independent of the random price that confronted the grower in the valuation for approved 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 $W_j \quad x_j \quad {}_j$, where W_i is the willingness to pay (WTP) of the *i*th individual for approved seeds, x_i are the correlates that are observed by the econometrician and $\square_i$ captures the correlates that are not observed by the econometrician. It is assumed that each individual receives a particular ? $_i$ 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 approved seeds, the probabilities of the three responses are:

[15] For a previous application of contingent valuation methods to Bt cotton, see Qaim and de Janvry (2003). Our bid design is different from theirs.

(a) $\Pr ob(Yes) \quad \Pr ob(W_j \quad 1600) \quad \Pr ob(\; x_j \quad _j \quad 1600) =$

$\Pr ob(\; _j \quad 1600 \quad x_j) \quad 1 \quad (1600 \quad x_j / \quad)$ where is the cumulative density of □.

(b) $\Pr ob(No, Yes) \quad \Pr ob(t_j \quad W_j \quad 1600) \quad F(1600) \quad F(t_j) \; =$

$(1600 \quad x_j / \quad) \quad (t_j \quad x_j / \quad)$ where t_j is the bid price offered to the grower in the follow-up question.

(c) $\Pr ob(No, No) \quad \Pr ob(\; x_j \quad _j \quad t_j) \quad \Pr ob(\; _j \; t_j \quad x_j) \quad (t_j \quad x_j / \quad)$

From the above, the log likelihood can be formed as:

$$\log L \quad \overset{T}{\underset{j\;1}{}} \quad \begin{array}{l} I_1 \ln[1 \quad (1600 \quad x_j / \quad)] \quad I_2 \ln[\quad (1600 \quad x_j / \quad) \quad (t_j \quad x_j / \quad)] \\ I_3 \ln[\quad (t_j \quad x_j) / \quad)] \end{array}$$

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

Following the exercise for approved seeds, specify the willingness to pay (for unapproved seeds) by the jth grower as $Z_j \quad X_j \quad _j$. 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) $\Pr ob(Yes, Yes) \quad \Pr ob(Z_j \quad 1600) \quad \Pr ob(\; x_j \quad _j \quad 1600) =$

$\Pr ob(\; _j \quad 1600 \quad x_j) \quad 1 \quad (1600 \quad x_j / \quad)$

(ii) $\Pr ob(Yes, No) \quad \Pr ob(t_j \quad Z_j \quad 1600) \quad F(1600) \quad F(t_j) \; =$

$(1600 \quad x_j / \quad) \quad (t_j \quad x_j / \quad)$ and

(iii) $\Pr ob(No, Yes) \quad \Pr ob(800 \quad Z_j \quad t_j) \quad (t_j \quad x_j / \quad) \quad (800 \quad x_j / \quad)$ and

(iv) $\Pr ob(No, No) = \Pr ob(Z_j \quad 800) = \quad (800 \quad x_j / \quad)$

Table 6 summarizes the responses from both contingent valuation exercises. In the case of approved 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 unapproved 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 unapproved seeds.

Table 6: Responses to WTP Questions

I. Approved seeds	
WTP Responses	Number of Growers
WTP > 1600 (Yes)	41
WTP > t (No, Yes)	16
WTP < t (No, No)	101
II. Unapproved seeds	
WTP Responses	Number of Growers
WTP > 1600 (Yes, Yes)	101
t < WTP < 1600 (Yes, No)	23
800 < WTP < t (No, Yes)	6
WTP < 800 (Yes, Yes)	27

Source: GIDR Farm Survey, 2004

6.1. 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 approved Bt seeds are much more expensive than **hybrid** seeds, a farmer's 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 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.

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: GIDR Farm Survey, 2004

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 approved seeds is summarized in Table 8. The willingness to pay (WTP) for approved seeds increases with farm size although at a decreasing rate. Irrigation and good soil quality also increase the WTP for approved 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 approved 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 WTP. On the other hand, experience with Navbharat Bt dampens valuations.

Farmers have a higher valuation of approved 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.

Table 8: Willingness to Pay for approved seeds

Variables	Coefficients /	Robust t-statstic	
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/)	0.00145	2.63	----
# of Observations	155		
Log-likelihood	-94.11		
Mean Willingness to Pay	Rs. 778		
Median Willingness to Pay	Rs. 880		

Source: GIDR Farm Survey, 2004.

The last column of Table 8 reports the betas, i.e., 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 approved seeds are overpriced and therefore have not been adopted widely[16].

Table 9 reports the estimates of the WTP function for unapproved F1 seed (Navbharat 151 and its variants). Many of the variables significant in the WTP equation for approved seeds are insignificant here[17]. 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 approved seeds.

Table 9: Willingness to Pay for F1 Unapproved seeds

Variables	Coefficients /	Robust t-stats	
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/)	0.00058	1.91	----
# of Observations	154		
Log-likelihood	-122.8		
Mean Willingness to Pay	Rs. 3050		
Median Willingness to Pay	Rs. 3028		

Source: GIDR Farm Survey, 2004

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 approved seeds. This variable has a negative sign indicating those who do not spray pesticides

[16] It should be noted that during the time of study, the only approved seeds were the varieties from Mahyco Monsanto and this finding applies to them. In later years, other legal Bt varieties have become available.

[17] 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.

have a substantially higher valuation of unapproved seeds. Like in the case of approved 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 approved 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 unapproved 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 approved seeds are sold, there could be an anchoring bias as growers could have perceived the question as eliciting a comparison between the unapproved F1 seed and the MM seed. We also estimated the WTP function based on the first response alone. 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 approved seeds.

7. Conclusions

Unapproved 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 seen this as proof of weak regulatory capacity and 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 unapproved 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, unapproved seeds perform just as well as approved seeds, if not better. Farmers value them highly and their valuations are strongly correlated with their aversion to pesticides. Enforcing the law would be unpopular with cotton growers. Why should the state government court such unpopularity?

Furthermore, the Bt gene contained in the unapproved varieties (cry 1 Ac) is the same as that in the approved Monsanto-Mahyco 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 according to straight forward political calculus[18].

[18] There is a long-term concern, however, that if the expression of Bt toxin is weaker in some varieties of unapproved 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.

The pressures to enforce biosafety and IPR 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 level. 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 law requires that all seed 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. In addition it will put in place another means of tracking varieties protected by the plant variety protection act.

However, the Bt cotton episode illustrates a generic issue with IPRs. While the government would like to establish IPRs, `de jure' or `de facto', to attract private investment in agricultural R&D, it has no incentive to enforce IPRs if the innovation is successful and promises large social gains with widespread adoption. Indeed, in the case of unapproved Bt cotton seeds, which have proven in farmers' fields to be as effective as the approved varieties, it is clear 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 IPR policies and the responsibility of the State government to enforce them makes the time consistency problem of IPRs more acute. The unapproved Bt seeds phenomenon is not the only instance where a State government has sought to erode the monopoly of approved seeds. As mentioned earlier, in the 2006 season, the Andhra Pradesh government imposed price controls on approved Bt cotton seeds citing farmer complaints about their high price.

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 (2004) 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 reward to technology owners 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 unapproved Bt cotton seeds, a "pull" program would compensate the owners of the technology in relation to the social gains from the diffusion of unapproved seeds. At the same time, the government could permit the Navbharat Bt cotton seeds and its variants to be evaluated for biosafety. Legalization would allow the state to monitor the expression of Bt traits without depriving growers of well adapted hybrids. The other social gain would be that the dissemination of the superior unapproved seeds would no longer be constrained by the word-of-mouth advertising and the informal social networks of the underground seed economy.

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Gota, Ahmedabad - 380 060. Gujarat, India
Tel: 91-2717-232623/366/368
Fax: 91-2717-242365
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