

# Empirical Analysis on the Impact of Private-sector R&D on Cotton Productivity in India

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Private seed firms in India have made significant investments in cotton breeding and biotechnology since the 1980s. These investments have paid off with a series of proprietary hybrids that were developed using the inbred lines based on public-sector research and breeding methods. The adoption of proprietary hybrids has rapidly increased since 1998, and by 2009-10, 95% of cotton acreage was under proprietary Bt hybrids. As a consequence of their adoption, average cotton yields have increased from 100 kg/ha in the 1950s to nearly 552 kg/ha for the 2013-14 planting season. While many micro-level studies have shown yield increases and pesticide reduction due to Bt hybrids, only a few have sought to estimate the differential impacts of proprietary hybrids from that of the Bt trait. This article seeks to estimate these differential impacts. For empirical estimation we used a unique data set from Francis Kanoi Marketing Research, who surveyed 20,000 small- and medium-sized cotton farmers over six time periods from 1998 to 2010. Our results show that adoption of proprietary cultivars, hybrids and Bt hybrids, were 20% to 38% higher than public hybrids and open-pollinated varieties. Additionally, pesticide use was reduced by the adoption of Bt hybrids. The financial returns to proprietary research were found profitable for firms, as were the economic benefits for society from private research, which are estimated to be between 36% and 44%. Our results suggest that government programs encouraging private-sector R&D could have substantial payoffs for private firms, as well as society in general.

**Key words:** Bt cotton, private sector, R&D, proprietary hybrids, GM trait, India.

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## Introduction

Over the last decade, investments in agricultural research by the private sector have grown rapidly in many developing countries (for example, see Hu, Liang, Pray, Huang, & Jin, 2011; Pray & Nagarajan, 2012b). While this has undoubtedly led to the availability and adoption of improved inputs and new technologies, there is concern that the needs of resource-poor farmers will be neglected since private firms may not regard them as a profitable market. Even if the firms do provide new technology to small farmers—and assuming that the farmers can afford it—a second concern is that firms will capture most of the economic surplus through monopoly pricing, thus leaving the farmers no better off. Firms have countered that without the ability to appropriate returns due, for example, to seed price policies they will have limited incentive to make further investment in new technologies, thus harming all farmers.

Yet claims by private firms that new cotton-seed technology has provided benefits have been met with skepticism. In India in particular there has been much criticism of proprietary hybrid cultivars and genetically

modified (GM) traits as technologies that enrich the seed companies at the expense of poor farmers. Several studies are doubtful of the evidence that yield gains can even be attributed to the GM insect-resistant *Bacillus thuringiensis* (Bt) traits. For example, Kuruganti (2009) suggests that observed production increases in cotton were caused by increased area under hybrids and irrigation rather than Bt technology adoption, and a recent report by the Agricultural Committee of the Indian Parliament declared that there have been no benefits to Indian farmers from Bt cotton (Agriculture Committee of the 50<sup>th</sup> Lok Sabha, 2012).

To analyze whether private firms develop technology that benefits smallholder farmers, this article analyzes data from a large survey of cotton farmers documenting the spread of proprietary cotton hybrids and GM cotton hybrids in India. Farmers' benefits and seed company profits from these hybrids and GM traits are calculated. We specially delineate the impact of hybrids from the impact of the GM traits. We show that smallholder farmers as well as larger farmers have captured benefits from both hybrids and the Bt trait. Using

our estimates on benefits to farmers and increased profits to seed companies as well as data on private firms' investments in research and development (R&D) we are able to calculate the rates of return to private investments in research. These calculations suggest that firms' investments R&D are profitable and are likely to grow in the future.

In the next section we briefly review the existing economic literature that quantifies the impacts of proprietary research on agri-businesses in India. This is followed by a section on R&D investments made on cotton by private firms in India and the innovations that came out of that research, followed by a section with empirical estimates of the impact of private-sector R&D on yields, income, and efficient input use on cotton in India. We then provide estimates of the financial and economics rates of return to private R&D. Finally, the article summarizes our conclusions and suggests policy options that could encourage private-sector investment in agricultural research for India.

## Literature Review

Studies of the impact of private-sector research and innovation on farmer and consumer income and the environment are limited (Beintema et al., 2009; Even-son, Pray, & Rosegrant, 1999; Kathage, Qaim, Kassie, & Shiferaw, 2012). The few studies available show private R&D increases agricultural productivity and generates positive economic rates of return (i.e., returns to farmers and/or consumers). Most studies related to the impact of private research in agriculture are based on the seed and biotech industries and show that seed/biotech innovations have increased yields, particularly cotton, maize, pearl millet, sorghum, and rice.

For example, Pray et al. (1991) measured the impact of private pearl millet and sorghum hybrids in the 1980s and found that farmers captured substantial economic gains from high yields of proprietary pearl millet and sorghum hybrids. A decade later, an econometric analysis of maize, sorghum, and pearl millet yields in the semi-arid tropics of central and southern India conducted by Ramaswami and Pray (2002) found that private hybrids raised yields after controlling for other factors such as public hybrids and high-yielding varieties. Matuschke and Qaim (2008) showed that innovation rates in seed markets increased after liberalization, and the adoption of proprietary hybrids of wheat and millet increased due to superiority of proprietary hybrids to most public-sector varieties.

It is often the case that the gains to farmers are greater than the gains to the companies that conduct the research (Pray et al., 1991; Pray & Ramaswami, 2001). Pray and Ribeiro (1991) estimated the economic rate of return to private plant breeding in India to be 38% or more, depending on the crop. For hybrid sorghum—a dry land crop—the seed companies that bred the new varieties captured at most only 12.5% of the benefits, with another 6% going to companies that marketed the seed. For hybrid pearl millet—another dry land crop—breeders and distributors combined captured only about 6%. The study estimated that farmers and consumers captured 80% to 95% of the benefits from private research on these crops.

A decade later, Pray and Ramaswami (2001) revalidated these results, finding that seed companies captured no more than 18.5% of the benefits from improved sorghum varieties. Similarly, for hybrid pearl millet, seed firms captured only about 6% of benefits, with more than 90% accruing to farmers. A study by Singh, Morris, and Pal (1997) on the maize seed industry in India found similar results regarding benefit shares to farmers versus seed supply companies. Recent studies by Pray and Nagarajan (2010, 2012a) on hybrid and Bt cotton and hybrid rice in India found that farmers accrue most of the benefits from private research investment followed by seed firms and companies that license GM technology providers.

In their research on private returns to rice hybrid in India, Pray and Nagarajan (2012a) show that the private sector is investing substantial funds in hybrid rice breeding. Eighty to 90% of the benefits from the proprietary rice hybrids developed by this research have been captured by farmers. Their empirical analysis also found that farmers in some of the poorest regions of India were benefitting from adopting proprietary rice hybrids. These are smallholder farmers in the eastern rice-growing areas of India who did not greatly benefit from the Green Revolution.

Field studies assessing the economic performance of Bt cotton adoption in India since its introduction in 2002 also provide evidence on the impact of private research. Both cross-sectional and panel estimates on farmer adoption of Bt cotton in different parts of India revealed that farmers have benefited from adopting Bt cotton technology through increased yields and reduced pesticide costs (Bennett, Kambhampati, Morse, & Ismail, 2006; Gandhi & Namboodri, 2006; Herring & Rao, 2012; Kathage & Qaim, 2012; Kouser & Qaim, 2011; Krishna & Qaim, 2012; Qaim & Zilberman, 2003; Sadashivappa & Qaim, 2009). These studies found that,

although Bt technology does not target increased yield, substantial yield increases were attributed to decreased pest damages. Reduced pesticide use and reduced costs associated with pesticide use offset higher costs of Bt seed. GM cotton increased incomes and improved the quality of life due to better health from less pesticide exposure.

One of the few analyses examining Bt technology performance as late as 2006-2007 is a study by Sadashivappa and Qaim (2009). Covering the first five years of Bt adoption in India and using three rounds of survey data between 2002-2003 and 2006-2007, they document reductions in pesticide use at around 30% and increased yields of 40% among Bt growers. Subramanian and Qaim (2009) also analyzed village-level welfare and distribution effects of Bt cotton adoption, documenting that, in addition to yield gains and decreased pesticide costs, the region as a whole showed improved aggregate employment (especially for hired female agricultural laborers) and increased household income among cotton growers. Each additional hectare of Bt cotton was shown to produce 82% higher aggregate incomes than obtained from conventional cotton. Sadashivappa and Qaim (2009) found that farmers' profits increased from US \$121 per ha in 2002-03 to US\$165 in 2006-07. India was estimated to have enhanced farm income from Bt cotton by US \$14.6 billion in the 11-year period from 2002 to 2012 and US \$2.1 billion in 2012 alone (Brookes & Barfoot, 2014).

In their panel analyses of 186 farmers in 2004-05 and 200-07 in Andhra Pradesh state comparing farming situations before and after the adoption of Bt, Herring and Rao (2012) found statistically significant increases in yields and income due to Bt adoption across social categories and farm size (i.e., small, medium, and large farmers). They concluded that in spite of increased seed cost, Bt cotton adopters had lower insecticide costs, higher yields, lower cost per quintal of cotton produced, and higher net income. Further, a study by Qaim and Kouser (2013) among 1,431 farm households in India from 2002 to 2008 found that the adoption of Bt cotton has significantly improved calorie consumption and dietary quality, leading to an increase in family income. The technology reduced food insecurity by 15-20% among cotton-producing households.

Gruère and Sun (2012) studied the contribution of Bt cotton adoption to long-term average cotton yields in India using a panel data analysis of production variables in nine Indian cotton-producing states from 1975 to 2009. They estimated that Bt cotton contributed to at least 19% of total yield growth over time, and particu-

larly around the period after 2005 with Bt cotton introduction. Kathage and Qaim (2012) compared four different periods (2002-04 and 2006-08) of Bt cotton performance among 1,655 farmers estimated that Bt cotton cultivation resulted in increased yield per hectare by 24%, and Bt farmers made 50% more profit on their cotton crop compared to non-Bt farmers.

In addition to yield and income benefits, Bt cotton adoption significantly reduced pesticide applications and poisonings, resulting in sizeable health benefits and cost savings since adoption in 2006 in India (Kouser & Qaim, 2011). Extrapolating these estimated results to India as a whole, they further estimate that Bt cotton now helps to avoid at least 2.4 million cases of pesticide poisoning every year, equivalent to a health cost saving of US \$14 million. These are lower-bound estimates of health benefits because they neglect the positive spillovers that Bt cotton entails. Alternative estimates suggest that Bt cotton may avoid up to 9 million poisoning incidents per year, which translates into a health cost saving of US \$51 million. Mayee and Choudhury (2013) noted a sharp decline in insecticide use, with the large-scale adoption of Bt cotton, from 5,748 metric tons of active ingredients in 2001 to 222 metric tons, resulting in a saving of roughly US \$135 million. In 2001, 46% of pesticide used in India was sprayed on cotton, compared to 17.2% in 2012. In any case, the positive health externalities are sizeable.

To sum up, small- and medium-sized farmers derived major benefits in terms of yield and income increases and pesticide cost reductions by the adoption of proprietary hybrids and biotech traits. The number of small farmers growing cotton increased from a few thousand in 2002-03 to 7 million farmers in 2011-12. Bt cotton halved insecticide usage from 46% of total insecticides used in 2001-02 to 21% of total insecticide use in 2010-11.

### **Private-sector Cotton R&D and Innovation**

Increased interest in cotton R&D is shown by the number of seed firms engaged in cotton crop improvement and their R&D investments (see Table 1). Between 1987 and 1995, private R&D investment in cotton increased from 40 million to 270 million Rupees; between 1995 and 2003 (hybrid development phase) it doubled and quadrupled from 2003 to 2009-10. In 2009-10, two companies invested more than 40% to 50% of total R&D in cotton crop improvement.<sup>1</sup> It appears that Bt cotton has stimulated total private seed industry investments in other crops also (see Column 2 in Table 1).

**Table 1. Private-sector R&D investment in cotton-crop improvement in India 1987 to 2009-10 (real Rupee terms).**

Year	Total R&D investment by seed firms in crop improvement	R&D investment in cotton crop improvement	Firms with cotton R&D	Sources
	Million Rupees	Million Rupees	Number	
1987	417	40	9	Pray et al (1991)
1995	1,549	270	27	Ramaswami, Pray and Kelley (2001)
2003	2,000	500-750	30-32	Biospectrum (2009)
2009-10	6,000	2,500-3,000	> 50 <sup>a</sup> (37 Bt cotton)	Pray and Nagarajan (2010)

<sup>a</sup> More than 50 companies are engaged in cotton crop improvement and breeding aspects, out of which 37 companies have directly engaged in Bt transformation.

**Table 2. Bt cotton approved events and private firms participation in India (2002-2012).**

Particulars	2002	2003	2004	2005	2006	2007	2008	2009 <sup>a</sup>	2010 <sup>b</sup>	2013 <sup>d</sup>
# of Bt hybrids approved	3	3	4	20	62	131	274	248	104	213 <sup>d</sup>
Events approved <sup>c</sup>	1	1	1	1	4	4	5	6	6	6
# of companies with Bt cultivars	1	1	1	3	15	24	31	33	37	40+

Source: Compiled from the Indian GMO Research Information Service (IGMORIS) website (n.d.); James (2008) and Adityendra (2007); GEAC (2009)

<sup>a</sup> Approved cultivars by GEAC exclusively for 2009

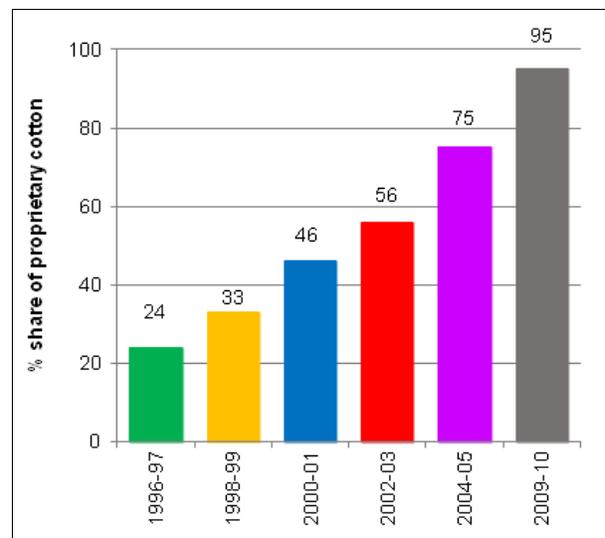
<sup>b</sup> Approved cultivars exclusively until May 2010

<sup>c</sup> Approved events are Monsanto (Bollgard I and Bollgard II); JK (IIT Kharagpur collaboration); Nath event (Chinese Bt event); Meta-helix; Dharwad-University of Agricultural Sciences (Central Institute of Cotton Research [CICR] collaboration). Events in the pipeline include Roundup Ready Flex trait by Monsanto, Dow AgroSciences, JK event, and Bayer CropScience.

<sup>d</sup> International Service for the Acquisition of Agri-biotech Applications (2014)

The private research investments started to pay off for companies and farmers when cotton hybrids started to spread in the late 1990s, and then Bt cotton became a commercial success starting in 2002. Figure 1 shows that proprietary hybrids accounted for only 24% of cottonseed sales in 1996-97 but had increased to 56% of the market by 2002-03 when the first Bt cottonseeds were introduced. All Bt cottonseed in India is hybrid seed. When Bt cotton became popular, the share of proprietary hybrids increased to more than 96% of the market in the 2009-10 growing season.

As a result of R&D investments, new Bt genes and new Bt hybrids were developed (see Table 2), with the number of GM hybrids increasing exponentially since 2006. New Bt genes began appearing in May 2006 when Monsanto-Mahyco Biotech (MMB) produced hybrids with stacked Bt genes, Bollgard-II. In the same year, two domestic seed companies—JK Agri Genetics Ltd. and Nath Seeds Ltd.—had Bt genes approved for commercialization. JK Agri Genetics developed “Event 1”

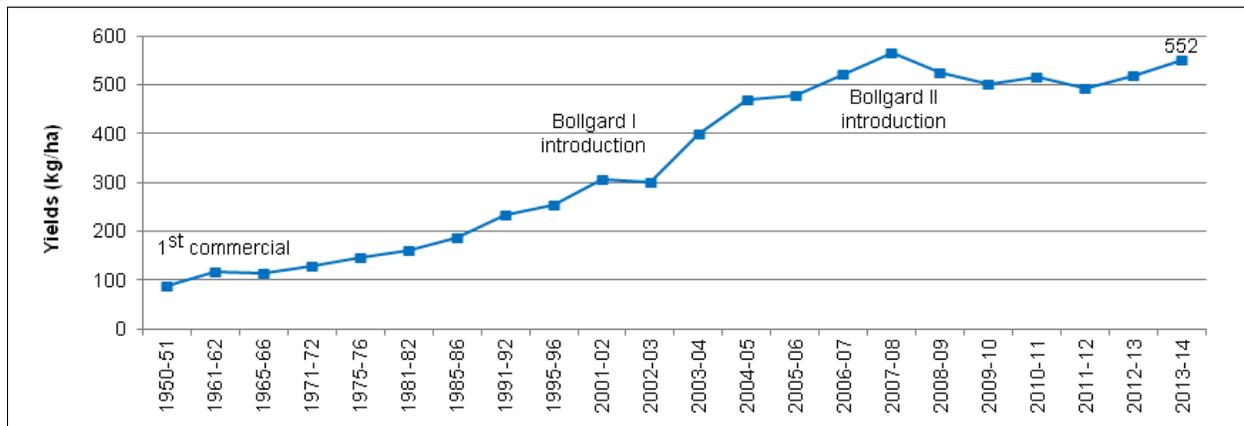


**Figure 1. Proprietary cotton hybrids market share (%).**

Source: Francis Kanoi Marketing Research (2010)

featuring the *cryIAc* gene sourced from the Indian Institute of Technology (IIT), Kharagpur. “Vishwanath,” a hybrid by Nath Seeds, contained a fusion *cryIAc/cryIAb* Bt gene, which was developed at the Chinese

1. Personal communication with seed industry sources by the authors and Rutgers University/National Seed Association of India (RU-NSAI) Seed Industry Survey, 2009-10.



**Figure 2. Cotton yields in India (kg/ha) 1950-51 to 2013-14.**

Source: *The Cotton Corporation of India Ltd. (2014)*

Academy of Agricultural Sciences (CAAS) and licensed to Biocentury Transgene Technology Company (BTTC), which is partially owned by CAAS. The Genetic Engineering Appraisal Committee (GEAC) of the Ministry of Environment and Forest (MOEF) approved six events of Bt cotton incorporating single and double genes in the 12-year period from 2002 to 2013. During this same time period, the GEAC approved 1,097 Bt varieties for commercial cotton cultivation. The event distribution of commercial cultivars includes Bollgard I (217 hybrids) and Bollgard II events from Monsanto (734 hybrids), Event-1 from JK Agri Genetics (42 hybrids), GFM Event of Nath seeds (100 hybrids), BNLA-601 event of the Indian Council of Agricultural Research (ICAR; 2 hybrids), and the MLS-9124 event of Meta Helix (2 hybrids; James, 2013).

Farm-level studies of the superiority of private hybrids and GM hybrids are substantiated by aggregate cotton-production data in India. After the 1971 release of the first commercial hybrids based on both private- and public-sector research, cotton yields showed gradual improvements (see Figure 2). Since 2002, aggregate yields increased more rapidly with increased adoption of Bt cotton and then leveled off in 2008 when the area under Bt cotton reached about 90% of the cotton area. Prior to Bt cotton, India's cotton yield was one of the lowest in the world—308 kg per hectare in 2001-2002 (global average for cotton production is 788 kgs per hectare [US Department of Agriculture {USDA}, Foreign Agricultural Service {FAS}, 2010]). As shown in Figure 2, the average yield of Bt cotton has increased to 552 kg/ha in 2013-14. Currently, India accounts for almost one-third of the global area (34 million ha) under cotton cultivation—more than 10 million hectares. However, in terms of production, India accounts for

only 20% of world production due to lower productivity per hectare (USDA FAS, 2010).

### Impact of Private Research on Cotton Yields and Pesticide Use

The empirical model used in this article to measure productivity of private R&D extends the work of Ramaswami and Pray (2002), which estimated factors influencing HYV and private hybrid adoption and productivity levels for coarse cereals using district level data. In our research, we attempt to move beyond comparing means of Bt and non-Bt farmers, in small sample, cross-sectional surveys to measuring the impact of hybrids and Bt on productivity (controlling for the variable input factors and other external inputs) using data on 20,000+ farmers over five time periods across all the main cotton-growing regions of India. We obtained a unique dataset collected by the Chennai-based market research firm, Francis Kanoi, consisting of state-level aggregate information across nine major cotton-growing states, covering 45 to 85 districts over five time periods (1998, 2000, 2002, 2004, and 2009). The dataset included data on 200 different cotton cultivars from the public and private sectors and other inputs use by 20,000+ farmers. The sample farmers were mostly small- and medium-sized farmers, cultivating anywhere between 0.5 ha and 5 ha. It also includes input and output prices during these time periods.

The number of farmers cultivating Bt cotton increased from 50,000 in 2002, to 100,000 in 2003, 300,000 in 2004, 1 million in 2004 and 6.3 million in 2010. In 2012, 7.2 million of the 8 million Indian cotton farmers planted Bt cotton. These are usually smallholder

**Table 3. Mean yields of cotton over time and technologies (kg of seed cotton yield/ha).**

Cultivar type	1998	2000	2002	2004	2009
Bollgard I				1,880	1,510
Bollgard II					1,520
Private hybrids	720	830	1,070	1,360	1,520
Public hybrids	610	700	890	1,190	1,110
OPVs/local varieties	430	890	930	1,400	1,200

Source: Francis Kanoi Marketing Research (2010); Bollgard I and II are hybrid Bt cotton cultivation.

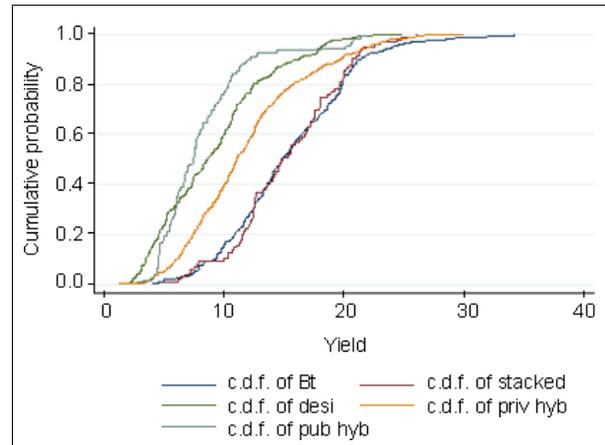
farmers cultivating cotton on an average agricultural area of 1.5 ha (James, 2012).

**Comparing the Means and Cumulative Distribution of Yields**

Table 3 shows that the mean yield differences between public and private hybrids were nearly 15 to 20% in all time periods after the introduction of cotton hybrids. The introduction of Bt technology (Bollgard I and Bollgard II) increased yields another 38% above existing hybrids in 2004 but was the same as non-Bt private hybrids in 2009. The cumulative distributions of cotton yields over different cultivar types such as public hybrids, private hybrids, Bt (Bollgard I) hybrids, and stacked (Bollgard II) hybrids over local/open-pollinated varieties (OPVs) across these time periods also show superior yields of hybrid technology and Bt cotton and the dominance of the private sector in yield enhancement of cotton in India (Figure 3). Another interesting result is that there is no obvious yield advantage of Bollgard II over Bollgard I (see Table 3 and Figure 3).

**Econometric Estimation on Yield and Pesticide Use**

In order to sort out the impact of different technologies from other factors across different time periods, we have modeled cotton yields using the Francis Kanoi dataset. For this article, we use data collected and aggregated at the state level across various types of cotton cultivars (more than 200 types), including hybrids and varieties, Bollgard I and II. Data was collected from 9 major cotton-growing states: Punjab, Haryana, and Rajasthan in the North region; Maharashtra, Madhya Pradesh, and Gujarat in the Central region; and Tamil Nadu, Andhra Pradesh, and Karnataka in the Southern region. To predict the impact of hybrids and biotechnology, we used a multi-variate, generalized least-squares regression using



**Figure 3. Cumulative distributions of cotton yields across cultivars and time periods.**

Source: Calculated by authors from Francis Kanoi Marketing Research (2010).

panel data estimation with time-fixed effects with an empirical specification as follows:

$$Yield_{(C,S)} = f(Private / Public Hybrids, Priv.Bt Dummy_{(C,S)} + Fertilizer use_{(C,S)} + Pesticide cost_{(C,S)} + Irrigation Cost_{(C,S)} + Location or regions Dummy_{(C,S)} + Time fixed effects) \tag{1}$$

$$Pesticide cost_{(S)} = f(Private / Public Hybrids, Priv.Bt Dummy_{(C,S)} + Fertilizer use_{(C,S)} + Yield_{(C,S)} + Irrigation Cost_{(C,S)} + Location or regions Dummy_{(C,S)} + Time fixed effects), \tag{2}$$

where *c*=cultivar (hybrids or varieties or Bt) and *s*=state.

Table 4 shows results from our regression analysis on the impact of private hybrids and other control factors described in the empirical estimation Equation 1. The overall impact of hybrids compared to OPVs/local varieties on yields was positive and highly significant, irrespective of public or private cultivars in all time periods. In addition, proprietary hybrids with no Bt yielded better than public hybrids. Also, yields of proprietary Bt hybrids were higher than proprietary non-Bt hybrids.

Cotton productivity significantly varies by region, with northern states (Punjab, Haryana, and Rajasthan) recording higher yields than the southern states of Andhra Pradesh, Karnataka, and Tamil Nadu and central regions of Maharashtra and Gujarat. Irrigation costs are positively related to yields, as is fertilizer application and pesticide cost, as expected. To estimate impact of

Table 4. Estimates of impact of private hybrids on cotton yields in India.

Variables	Unit	Coeff	Std. err	Significance level
<b>Variety/hybrids</b>	Public hybrids	2.118	0.435	1%
<b>Base category is 'local/OPVs'</b>	Private hybrids	3.418	0.323	1%
	Private Bt hybrids	4.134	0.408	1%
<b>Location effects</b>	North India	2.066	0.4084	1%
<b>Base category is 'South India'</b>	Central India	-2.399	0.3235	1%
<b>Pesticide costs</b>	'000 Rs/ha	0.0003	0.0001	5%
<b>Irrigation costs</b>	'000 Rs/ha	0.0016	0.0002	1%
<b>Fertilizer use</b>	Quintals/ha	0.0010	0.0004	5%
<b>Time-fixed effects</b>	Year 2000	2.855	0.409	1%
	Year 2002	4.017	0.409	1%
	Year 2004	7.152	0.422	1%
	Year 2009	3.679	0.538	1%
	<b>Number of observations</b>		1,082	
	<b>F(12, 1069)</b>		144.84	
	<b>Prob &gt; F</b>		0.0000	
	<b>R-square</b>		0.6192	
	<b>Adjusted R-square</b>		0.6149	

Notes: Dependent variable=Variety-wise cotton yield in quintals per hectare

Table 5. Estimates of impact of private hybrids on cotton pesticide use in India.

Variables	Unit	Model 1	Model 2	Model 3
<b>Variety/hybrids</b>	Public hybrids	-363**	-225	-159
<b>Base category is 'OPVs/local'</b>	Private hybrids	-187*	-218*	-75
	Private Bt hybrids	-234*	-722***	-558***
<b>Location effects</b>	North India	-941***	-595***	-525***
<b>Base category is 'South India'</b>	Central India	-1,867***	-1,726***	-1,822***
<b>Yield</b>	q/ha	29***	34***	
<b>Irrigation costs</b>	'000 Rs/ha	0.392***	-0.049	0.006
<b>Fertilizer use</b>	q/ha	1.732***	1.303***	1.340***
<b>Time fixed effects</b>	Year 2000		94	
	Year 2002		133	
	Year 2004		-106	
	Year 2009		-1,647***	
<b>Constant</b>		2,990***	3,239***	3,435***
	<b>Number of observations</b>	1,082	1,082	1,082
	<b>F(12, 1069)</b>	65.79	74.43	82.30
	<b>Prob &gt; F</b>	0.0000	0.0000	0.0000
	<b>R-square</b>	0.4248	0.3569	0.3491
	<b>Adjusted R-square</b>	0.4183	0.3521	0.3449

Notes: Dependent variable=Pesticide costs (Rupees/ha)

\*, \*\*, \*\*\* Denotes statistical significance ( $P > t$ -value) at the 1%, 5%, and 1% levels, respectively.

private hybrids and the introduction of Bt technology on the use of cotton pesticides in India, we used simple OLS regressions to estimate Equation 2. The results of

three different specifications of the model are shown in Table 5.

The empirical analysis shows that one key factor in reducing overall pesticide cost in all the above specifi-

cations is use of private Bt hybrids. Private Bt hybrids have significantly lower pesticide costs per hectare compared to other cultivar types in all models. When we move from the time-fixed effects model (Model 1) to Models 2 and 3—which do not include the time dummies—the coefficient on private Bt hybrids goes from a decline of Rs 234/ha to declines of Rs 722 or Rs 558/ha, depending on whether the yield per ha variable is included. In Model 1, the time dummy for 2009 (when Bt cotton occupied nearly 90% of the overall cotton area cultivated in India) along with the lower Bt coefficients in the other models, clearly shows the impact of Bt cotton in that period. The other variables are as expected or insignificant and the statistics that show the explanatory power of the models is adequate.

The shift in technology by farm households from the use of varieties to hybrids and GM cotton cultivars (Bollgard I and II), driven by the private sector in recent years, has reduced the land needed (by increasing yields) and reduced pesticide costs, which are the major costs of cotton cultivation in India and elsewhere. Most non-GM cotton cultivars are affected by bollworms that significantly reduced yields. In India the private-sector cultivars that contain the MMB Bt, plus the Bts from other firms since 2002 have significantly reduced pesticide use in cotton cultivation and have also indirectly improved cotton productivity by decreased levels of damage to cotton output (lint) due to pest infestation.

### **Economic Returns to Private Investment in Cotton**

Pray, Nagarajan, Huang, Hu, and Ramaswami (2011) calculated the share of benefits derived by different stakeholders (seed firms, technology providers) in the Bt cottonseed supply chain in India (Table 6). They found that farm-level profit increased substantially since 2002 with the adoption of Bt cotton. Farm profits account for nearly 85% to 90% of total revenue earned by the entire Bt cotton industry (including technology provider and seed firms' profits). Biotech companies and seed companies benefitted from introducing this technology through increased profits, but farmers who adopted BT cotton, in aggregate, were the biggest winners.

Given the dominance of private-sector R&D and coverage in hybrids (refer to Tables 1 and 2 and Figure 1) and Bt technology development for cotton in India, we further estimated returns (economic and financial) to the private-sector investment in cotton cultivar development. Our returns calculations are based on assumption

**Table 6. Shares of total revenue to farmers, technology providers (MMB), and seed firms.**

Year	Share of stakeholders in net revenue		
	Farmers	Firms	MMB
	Percentage (%)		
2002-03	71.2	18.2	10.6
2003-04	60.8	24.8	14.4
2004-05	56.5	27.7	15.8
2005-06	58.1	26.9	15.0
2006-07*	95.8	1.9	2.3
2007-08	93.4	3.1	3.6
2008-09	90.4	4.2	5.4
2009-10	89.4	4.4	6.3

Source: Calculated from assumptions based on Industry estimates of total seed packets sold over years (Pray & Nagarajan, 2010).

\* refers to year of seed price-control imposition in India.

that across cotton-growing regions in India, adoption of proprietary hybrids and then Bt hybrids led to increases in (mean) yields. Our regressions estimate that the yield level of private hybrids was 341 kg/ha higher than existing OPVs or local cultivars, and that Bt proprietary hybrids were 413 kg/ha higher than OPVs (refer to Table 4). Two important points emerge from estimates:

- Private investments in cotton R&D in India were profitable for firms. We estimate an internal rate of return of 16% to all firms' investment in cotton R&D in India during 1987-2010. To calculate this return we used R&D expenditures from 1987 to 2010 based on the data in Table 1 as the research investments and the increased net revenue of firms due to higher prices and sales of hybrid cotton and Bt hybrid cotton during the same period. The 16% rate of return compares favorably to the interest rates at which firms are able to borrow money in India and was also considerably better than the rates of return to investments in hybrid rice, which were 7% to 8% (Pray & Nagarajan, 2012).
- Economic rates of returns (the benefits that go to farmers calculated as the value of the increased yields of cotton due to hybrid and Bt hybrids minus the increased seed cost plus the increased net revenue of the seed and biotech industries from 1987 to 2010) to private investments in research are much higher during the same period (1987-2010). The economic returns to investing Rupees in R&D to incorporate Bt into existing proprietary hybrids was

about 36%. The combined economic returns of developing proprietary hybrids plus transforming them into Bt hybrids was around 44%. This is similar to the economic rates of return to public-sector research on cotton in India (Chand, Kumar, & Kumar, 2011), suggesting that both government investments in R&D and government programs to encourage private firms to invest in R&D are good investments.

Our empirical analysis of returns to private research investments in cotton agree with previous studies conducted in India (Pray et al, 1991; Pray & Nagarajan, 2010; Pray & Ramaswami, 2001; Ramaswami, Pray, & Kelley, 2001). The private research investments provided benefits to farmers who adopt proprietary hybrids. This evidence suggests that farmers are rational in their decisions to adopt proprietary hybrids and Bt hybrids because they—not seed companies—capture most of the benefits from the investments in crop research.

## Conclusions

Contrary to claims that private research has little or no benefit for smallholder farmers in developing countries and that the entire yield increases are due to public hybrids not the introduction of biotechnology, this research shows significant positive impacts on cotton yields and reduced pesticide use of smallholder farmers due to the adoption of private hybrid cottonseed and biotechnology developed and adapted by private research in India.

In a large survey of some 20,000+ households, where more than 80% of households surveyed were small- (< 2.5 ha) or medium-sized (between 2.51 and 5 ha) farms in the nine most important cotton-growing states, the mean yields of private hybrids were nearly 15% to 20% higher than public hybrids. The introduction of Bt technology increased yields another 38% above existing hybrids in 2004 but was the same as non-Bt private hybrids in 2009.

Econometric modeling using the same data allowed us to focus in on the impact of private hybrids and Bt while controlling for other factors. The models showed that hybrid yields were significantly higher than OPVs/local varieties. In addition, private hybrids with no Bt yielded better than public hybrids, and the yields of Bt hybrids were higher than yields of non-Bt hybrids. Another econometric model of cotton pesticide use showed that the adoption of Bt hybrids reduced overall pesticide costs.

To test whether the private research that increased cotton yields of smallholder farmers was financially sustainable, the rate of return to private-sector cotton research was calculated to be 16%, which is considerably higher than the cost of financing during this time period. This suggests that these investments in private research will continue to grow in the future, which is good news for smallholder farmers. Our calculations that the economic benefits for society of private research were between 36% and 44% indicates that the government of India and state governments should be supporting policies that will encourage more private-sector agricultural research.

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